AD-A278 707

Defense Nuclear Agency
Alexandria, VA 22310-3398

DNA-TR-93-116-V1

HEMTT Dynamic Sensitivity to Small Obstacles at Low Velocities
Volume 1—Field Tests

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April 1994

Technical Report

CONTRACT No. DNA MIPR 92-681

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
940401

3. REPORT TYPE AND DATES COVERED
Technical 920501 – 930228

4. TITLE AND SUBTITLE
HEMTT Dynamic Sensitivity to Small Obstacles at Low Velocities
Volume 1—Field Tests

5. FUNDING NUMBERS
C - DNA MIPR 92-681
PE - 4613
PR - AE
TA - CB
WU - DH926810

6. AUTHOR(S)
Randolph A. Jones

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Nuclear Agency
6801 Telegraph Road
Alexandria, VA 22310-3398
OPAC/Simelton

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
DNA-TR-93-116-V1

11. SUPPLEMENTARY NOTES
This work was sponsored by the Defense Nuclear Agency under RDT&E RMC Code B4613D AE CB 00085 OPAC 2600A 25904D.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

U.S. Army Waterways Experiment Station conducted dynamic tests using the M977 Heavy Expanded Mobility Tactical Truck (HEMTT) in both the empty and loaded configuration crossing low profile linear obstacles in both vehicle tracks. The obstacle heights were: 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50 and 3.00 inches. The tests were designed to simulate the process of weigh-in-motion (WIM). The data collected were also used in a separate study which validated a 2-dimensional dynamics model created, using the VEHDYN 3.0 code. The instrumentation consisted of: vertical accelerometers; rate transducers; and string potentiometers. The testing was conducted at two low velocities: 1.8 mph and 4.5 mph. Each test was repeated three times to achieve a data base on the range of vehicle responses to similar tests.

The data were reduced in the form of: time histories, frequency analysis using an FFT, peak dynamic values versus obstacle height, maximum frequency amplitude versus obstacle height.

14. SUBJECT TERMS

Low Velocity	Validation	HEMTT
Vehicle Dynamics	VEHDYN 3.0	Pitch Rate
Weighing-In-Motion	Computer Simulation	Accelerometers

15. NUMBER OF PAGES
158

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
NCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-280-5500

Standard Form 298 (Rev.2-89)
Prescribed by ANSI Std. 239-18
298-102

CLASSIFIED BY:

N/A since Unclassified.

DECLASSIFY ON: N/A since Unclassified.

PREFACE

The work reported herein was sponsored by the Defense Nuclear Agency and was conducted during the period from March, 1992 to August, 1992. This effort was performed in support of the Pavement Systems Division's (PSD) Weigh-In-Motion (WIM) research program to examine the vehicle dynamics caused by crossing a low profile linear obstacle.

The study was conducted at the U.S. Army Engineer Waterways Experiment Station (WES) under the general supervision of Dr. W. F. Marcuson III, Chief, Geotechnical Laboratory (GL), and under the direct supervision of N. R. Murphy, Jr., chief, Mobility Systems Division (MSD), and R. H. Gillespie, chief, Mobility Investigations Branch, MSD. The field test program was conducted by R. A. Jones, MSD. Field test support was provided by R. H. Johnson, D. E. Mcclurg, D. E. Strong, A. E. Roberson, R. N. Tennent, T. J. McCaffery, MSD; L. B. Naron, and W. C. Fryer, Instrumentations Service Division. The report was prepared by Mr. Jones.

The WIM research program was directed by Dr. A. J. Bush III, Chief, Criteria Development and Applications Branch (CDAB), and Mr. R. M. Bradley was the principal investigator. Technical guidance was provided by Mr. D. C. Creighton, MSD.

Dr. Robert W. Whalin was Director of WES during preparation of this report. COL Leonard G. Hassell, EN, was Commander.

CONVERSION TABLE

Conversion Factors for U.S. Customary to metric (SI) units of measure.

Multiply	By	To Obtain
g's (acceleration of gravity)	9.80665	meters per seconds squared
Hertz	6.283185	radians per second
feet	0.3048	meters
inches	0.0254	meters
pounds (force) inches	0.1129848	newton meters
miles (U.S. statue)	1.609347	kilometers
pounds (force) per square foot	47.88026	pascals
pounds (mass)	0.4535924	kilograms

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

FIGURES

FIGURES (Continued)

TABLES

SECTION 1
INTRODUCTION

1.1 BACKGROUND.

In April 1992 the Pavement Systems Divisions (PSD) contacted the Mobility Systems Division (MSD), both of the Geotechnical Laboratory, Waterways Experiment Station (WES), and requested assistance explaining the dynamic effects in the chassis of heavy military wheeled vehicles when traversing very low profile linear obstacles (0.25 inch to 1.00 inch in height). This request originated through research the PSD was conducting for the Defense Nuclear Agency (DNA) on dynamic weigh-in-motion (WIM) scales. These WIM scales had to meet weight and accuracy specification requirements set forth by the DNA. The WIM scale had to weigh 50 pounds or less, be transportable by one person, and achieve a 1 percent weighing accuracy. To obtain such a light design and low error tolerance with available technology required the WIM designs to be very low in profile and able to account for the natural dynamic oscillation of the vehicle (since the vehicle would be weighed while in motion).

PSD was conducting research on two different WIM designs. The first used seven piezoelectric strips to detect the weight of the vehicle. Each piezoelectric strip was approximately 2.00 in. long (in the direction of vehicle travel) and wider than the vehicle (from the left to right side of the vehicle). The second used fiber optics encased in a ramp platform approximately 1 ft long and wider than the vehicle. To obtain the most accurate measurements the WIM devices had to continuously measure the vehicle's downward force under the tire for one complete natural frequency wavelength. For example, if the vehicle to be weighed had a 3 Hz natural frequency and crossed a WIM device at 2.0 mph, the device would have to be approximately 12 in long to capture the vehicle's weight during 1 complete natural frequency cycle. If the device is unable to weigh the vehicle for one continuous natural frequency cycle, the vehicle might roll across the WIM device on the upper amplitude of its natural frequency cycle, causing the WIM device to report a light weight, or report a heavy weight if the vehicle were weighed during the lower amplitude of its natural frequency cycle. Also, the amount of vertical chassis disturbance caused by the WIM device acting as a small linear obstacles needed to be quantified. If the WIM device caused enough dynamic disturbance to the vehicle's chassis the dynamic disturbance would have to be considered in

the final WIM weight output. If these dynamic disturbances and frequency oscillations could be measured or predicted, the WIM devices could implement frequency algorithms to adjust the final acquisition process and weight output.

The PSD and DNA were interested in using vehicle dynamic models to determine the vehicle dynamic and frequency responses to the WIM devices for a variety of different vehicles. A validated vehicle dynamics model would also allow for the analysis of different WIM designs.

The MSD demonstrated two vehicle dynamic packages in answering the request from the PSD and DNA. The Vehicle Dynamic Module (VEHDYN), a planar vehicle dynamics model which is used in the NATO Reference Mobility Model and the [1]Dynamic Analysis and Design Systems software, a planar or spatial versatile dynamics package. The VEHDYN module was selected for initial analysis since the style of weigh-in-motion technique envisioned was essentially a planar problem and because of the ease of vehicle model creation in the VEHDYN environment.

To determine the dynamic responses of a heavy military vehicle when impacting a WIM device, and to determine the accuracy and sensitivity of the VEHDYN module, vehicle field tests were scheduled and conducted from March to August 1992. The U.S. Army M977 Heavy Expanded Mobility Tactical Truck (HEMTT) was selected as the study vehicle for its' design, availability and weight capacity.

1.2 PURPOSE.

The purposes of this study were to:

a. Instrument a U.S. Army M977 HEMTT with appropriate instrumentation to determine the vehicle's response to very low profile linear obstacles.

b. Conduct a sufficient number of vehicle tests at two slow velocities over varying height low profile linear obstacles to determine the amplitudes and frequencies of the vehicle's response to the obstacles.

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[1]Marketed by Computer Aided Design Software Inc, (CADSi)

c. Determine if the obstacles cause sufficient disturbance to the chassis of the vehicle to alter the accuracy of the WIM devices.

d. Collect a sufficient amount of dynamic disturbance data for use in validating a VEHDYN HEMTT vehicle model.

e. Conduct vehicle drop tests to determine the natural frequencies of the vehicle and supply information for vehicle modeling purposes.

f. Use the experimental data to draw conclusions on the vehicle's response to obstacle height and vehicle speed.

1.3 SCOPE.

WES conducted dynamic tests using the M977 HEMTT in both the empty and loaded configuration. The test consisted of the vehicle traversing low profile linear obstacles ranging in height from 0.25 in. to 3.00 in. The test obstacle height exceeded the WIM devices height for model validation purposes. The tests were conducted at two speeds. The slower speed was approximately 1.8 mph and the faster speed was approximately 4.5 mph. Each test was repeated three times to achieve a data base on the range of responses to similar tests. A total of 96 low profile dynamic tests were conducted with the M977 HEMTT.

The M977 HEMTT was used in dynamic drop tests to determine the natural frequencies of the vehicle. The drop test information was also used to calculate the spring and damper constants which were then used for suspension characteristics in the VEHDYN model.

SECTION 2

DESCRIPTION OF TEST VEHICLE

2.1 GENERAL.

The Heavy Expanded Mobility Tactical Truck (HEMTT) system, shown in Figure 2-1, is the U.S. Army's work horse. It is a wheeled 8x8, 10- to -12 ton payload truck with good on- and off-road mobility. The HEMTT is diesel powered with a fully automatictransmissic incorporates four driving axles with low profile super single radial tires which enhance the vehicle's soft soil and traction performance. The truck incorporates a cab forward engine design and is fielded in five configurations. The M977 is a Ammunition Resupply Vehicle with a light weight crane for load-unload capability. The other HEMTT configurations are; a 2,500 gallon fuel Tanker (M978); a Tractor (M983); a Wrecker/Recovery Vehicle (M984); and a Missile/Rocket Resupply Vehicle with heavy duty crane (M985). The M977 HEMTT configuration was selected as the test vehicle for its design, availability, and weight capacity.

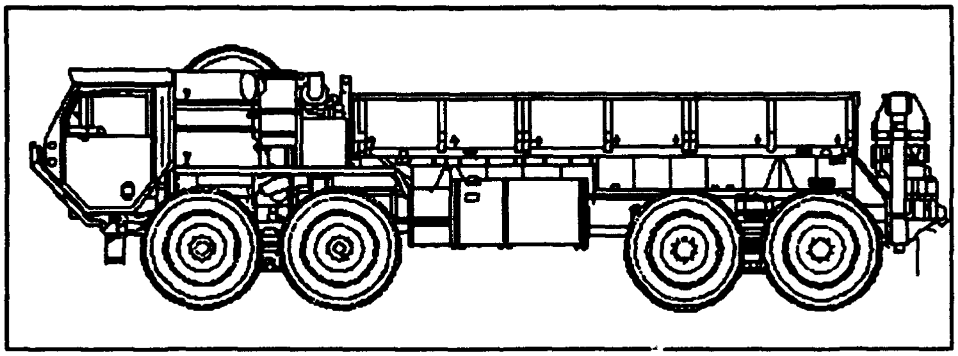

Figure 2-1. Left side view of M977 HEMTT.

2.2 VEHICLE CHARACTERISTICS.

The M977 uses a walking beam suspension, shown in Figure 2-2, in both the front and rear pairs of axles. The vehicle's suspension incorporates a floating cross tube which ties the left and right two walking beams together. The walking beam also rotates about this tube. The floating cross tube limits the amount of lateral axle and suspension displacement. The clamp

and bushing design, which fastens the tube to the walking beams, minimizes the amount of rotational resistance to just the resistance of the bushing. The center of each walking beam is attached to the center of a leaf spring system. Each end of the leaf spring system is attached to the chassis. A shock absorber is located between the chassis and each axle. The walking beam suspension allows each axle to rotate about the center of the walking beam. The walking beam can also move vertically by compressing the leaf spring system. The vehicle utilizes duel axle steering on the front pair of axles. This gives the vehicle a smaller turning radius than a single axle steer system. The M977 comes equipped with Michelin 1600R20XL tires. The Michelin XL series are designed for off-road performance and use an aggressive "S" tread pattern (Michelin, 1986).

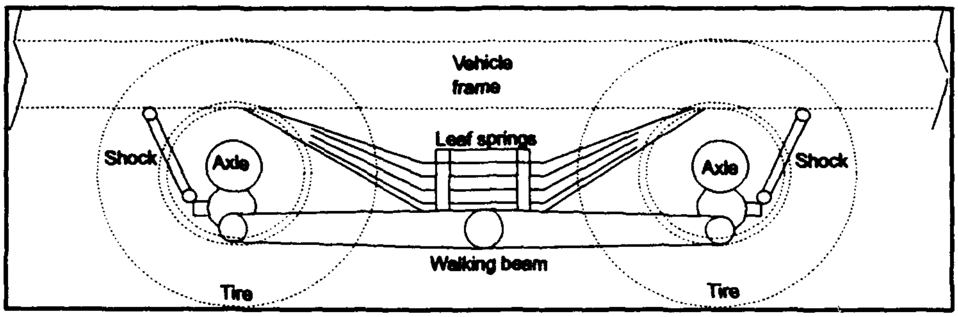

Figure 2-2. Side view of HEMTT walking beam suspension.

The M977 was weighted to simulate a full payload of 22,000-lb. Steel blocks of 1,000-lb each were loaded in the cargo area and configured to simulate a distributed loading. The resulting loaded vehicle was weighed using static cantilever beam truck scales and weighed 60,106-lb. The empty vehicle was weighed with the same scales and weighed 38,000-lb. The center of gravity (c.g.) of the empty vehicle was located 125 in. rear of the front axle, and the c.g. of the loaded vehicle was located 144 in. rear of the front axle. Table 2-1 present the vehicle's characteristics.

Table 2-1. M977 HEMTT Vehicle Characteristics.

Characteristics	Dimension
Gross vehicle weight, lb	60,106
Curb vehicle weight, lb	38,000
c.g. empty vehicle from front axle, in.	125
c.g. loaded vehicle from front axle, in.	144
Vehicle length, bumper- to- bumper, in.	400.3
Vehicle width, mirrors folded in, in.	96
Axle 1 to axle 2, in.	69
Axle 1 to axle 3, in.	210
Axle 1 to axle 4, in.	270
Overall height to top of spare tire, in.	112
Ground clearance, in.	13
Fording depth, in.	48
Tire size, Michelin	1600R20XL

SECTION 3
VEHICLE INSTRUMENTATION

3.1 ACCELEROMETERS.

A total of seven accelerometers were used to measure the vertical accelerations along the vehicle. Figure 3-1 shows the location of all vehicle instrumentation in the "Y-Z" plane. Table 3-1 presents the location of the accelerometers in terms of the global axis. Each chassis location was chosen to determine the dynamic effects on the vehicle relative to the vehicle's c.g. Four accelerometers were used to instrument the vehicle's suspensions on the left side. One accelerometer was located on the top center of each axle and placed as close to the wheel as possible. Accelerometers were also located at the vehicle's c.g., on the vehicle's side-to-side centerline at the rear of the cargo area, and on the floorboard under the driver's seat. The accelerometer at the rear of the vehicle was used to measure vertical acceleration caused by vehicle pitch during the dynamic event. The accelerometer under the driver's seat was used for VEHDYN validation purposes. The accelerometer at the c.g. was used to measure the vertical acceleration without vehicle pitch. Vertical acceleration measurements were taken at each point of interest before the vehicle impacted the obstacle and during the dynamic event.

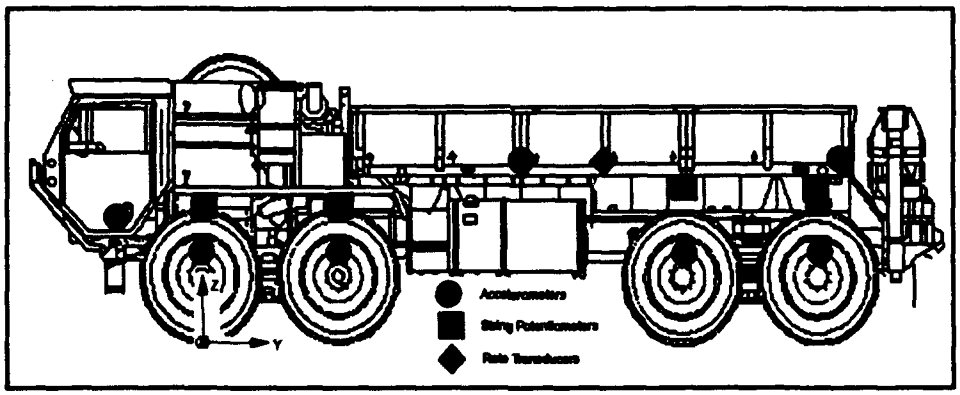

Figure 3-1. Location of vehicle instrumentation and axis.

The instrumentation was calibrated to detect minute changes in the vehicle's dynamic responses. For the accelerometers this meant magnitudes of less than 0.1 g's and up to 1.5

g's. The instruments used were selected for this range of dynamic operation. The dynamic data collected, in the form of time histories, was excellent. The signal traces were clean and their response quality was very good.

The vehicle's global axis is set with the "X","Y", and "Z" zero point starting at the side-to-side centerline of the vehicle and on the centerline of the front axles but lower to the ground level. The Y axis runs the length of the vehicle with positive towards the front of the vehicle. The X axis runs side-to-side with positive towards the right (passenger side). The Z axis is the vertical axis with positive going up. The "right-hand-rule" is used to determine positive and negative rotations.

Table 3-1. Accelerometer Locations.

Location of Instrument	X Axis Distance Inches	Y Axis Distance Inches	Z Axis Distance Inches
Floorboard under the driver's seat	-32.5	35.0	44.5
c.g. loaded c.g. empty	0.0 0.0	-143.9 -124.9	82.5 70.0
Side-to-side centerline at rear of cargo area	0.0	-283.0	70.0
Left suspension #1 axle	-30.0	0.0	33.3
Left suspension #2 axle	-30.0	-69.0	33.3
Left suspension #3 axle	-23.0	-210.0	29.3
Left suspension #4 axle	-23.0	-270.0	29.3

3.2 RATE TRANSDUCERS.

Three rate transducers were employed to measure the vehicle's pitch, roll, and yaw rates during testing. Table 3-2 presents the location of the rate transducers in terms of the global axis. These devices measure the rate or angular velocity at which the pitch, roll, and yaw occur. The tests were designed to simulate the actual weighing process, therefore they were basically two dimensional tests. The left and right side of the axles impacted the obstacle simultaneously producing only pitch. But, since the dynamic quantities measured during testing were very small in magnitude, the vehicle roll and yaw had to be measured to determine if they were negligible. Since each device measures the movement in a two dimensional plain, the placement of these devices was not critical. Therefore, they were attached to the center of the vehicle's cargo area.

Table 3-2. Rate Transducer Locations.

Location of Instrument	X Axis Distance inches	Y Axis Distance inches	Z Axis Distance inches
Pitch Transducer Roll Transducer Yaw Transducer	0.0	-167.0	70.0

3.3 STRING POTENTIOMETERS.

To measure the relative displacement of each suspension with respect to the chassis, each left side suspension was instrumented with a string potentiometer (string pot). Table 3-3 presents the location of the string pots in terms of the global axis. A string pot uses a very thin steel cable (string) attached to a rotational spring to detect any movement. The potentiometer changes output voltage as the cable is pulled out or retrieved. The string pot was calibrated to produce a known voltage for a known linear cable output or retrieval. A string pot was attached to the vehicle's chassis directly above each axle on the left side of the

vehicle. Each string was attached to the axle directly below each pot. This produced a vertical and linear displacement path for each pot's string. Measurements were taken with the string pots before and during the obstacle event.

Table 3-3. String Potentiometer Locations.

Location of Instrument	X Axis Distance inches	Y Axis Distance inches	Z Axis Distance inches
String Pot #1 axle	-27.3	0.0	N/A
String Pot #2 axle	-27.3	69.0	N/A
String Pot #3 axle	-22.0	210.0	N/A
String Pot #4 axle	-21.3	270.0	N/A

3.4 EVENT LASER.

A photoelectric sensor was used to locate the vehicle inside the test course at several critical locations. Table 3-4 presents the location of the photoelectric sensors in terms of the global axis. The photoelectric (event laser) sensor operates like a price scanner at most food stores. The sensor emits a beam of laser light and detects the reflection of the light back to the sensor. Reflector tape 6 in. wide was used to mark critical points within the test course. These reflectors were placed on the ground with the reflector side facing up. The event laser was attached to the front center of the vehicle and pointed towards the ground. The laser has a scan distance of 30 ft and a maximum response time of 1 millisecond (0.001 sec). As the vehicle rode over the reflector tape the event laser would detect the tape and turn on. When the beam passed by the tape the event laser would turn off. The event laser's voltage output was measured during vehicle testing and registered as an on-off, 1 volt pulse trace. Therefore, when the time history trace revealed a step function, the event laser was over a reflector tape and the location of the vehicle could be determined.

Table 3-4. Photoelectric Sensor Location.

Location of Instrument	X Axis Distance inches	Y Axis Distance inches	Z Axis Distance inches
Event Laser	0.0	73.0	N/A
Pipper Encoder	N/A	N/A	N/A

The photoelectric sensor was also used as a pipper generator to measure the vehicle's velocity. A photoelectric sensor (pipper) was attached to the frame of the vehicle and pointed to the main drive shaft of the vehicle. Two thin strips of reflector tape were attached to the drive shaft on opposite sides. As the drive shaft rotated the pipper sensor would detect the tape and generate an on-off step function. The calibration of the system was performed at a very slow speed where slip could not occur to determine the horizontal distance the vehicle would travel for one pip. During testing the pipper was monitored prior to and throughout the test event to determine the continuous velocity of the vehicle.

SECTION 4

TESTS CONDUCTED AND DATA COLLECTED

4.1 VEHICLE DROP TESTS.

It has been shown that a vehicle's suspension characteristics can be determined from the acceleration traces of the vehicle's chassis caused by a single step function force, such as a drop test (Durham and Murphy, 1976). Drop tests were conducted with the M977 HEMTT to collect acceleration traces of the vehicle's chassis. The acceleration traces were used to calculate the spring and damper constants of the vehicle which were used for VEHDYN model input (Creighton, 1993).

The vehicle's instrumentation for obstacle testing was sufficient for the dynamic drop tests. The weight of the vehicle in both the empty and loaded configuration was greater than the lift capacity of the MSD overhead crane. Therefore, the drop tests were designed to determine the front suspension characteristics in one test and the rear suspension characteristics in a second tests. Also, the design specification of the vehicle's springs and dampers called for stiffer suspension components in the rear of the vehicle. The testing techniques used produced data which verified these differences.

A device designed to allow the quick release of a cable was attached to a lift cable. This cable was then attached to lift points on the front of the vehicle. The quick release device was connected to the overhead crane. A cable attached to a cantilever on the quick release device was secured to a forklift. (Pulling the cantilever caused the device to release the cable holding the vehicle.) The vehicle was lifted by the crane to allow the front four tires to clear the ground surface by approximately 3 in. The forklift then pulled on the cable attached to the cantilever causing the quick release device to drop the cable attached to the vehicle. The accelerometers on the vehicle's chassis were monitored until the vehicle's suspension damped all motioned caused by the event. This technique was repeated three times for both the front and rear drop tests.

4.2 OBSTACLE TESTS.

4.2.1 Test Site.

The obstacle tests were conducted on WES test facilities. The test site was located on a section of paved asphalt with sufficient length for approach and exit lanes. The approach and exit lanes allowed the vehicle to reach the desired test speeds and provided a sufficient distance for the vehicle's suspension to dampen the dynamic event.

4.2.2 Obstacle Designs.

The obstacles were design to simulate the WIM devices and supply sufficient tests heights to validate the dynamic vehicle model. The obstacles were made of plywood and were the width of the test vehicle. The obstacles were two ft in length and ranged in heights up to 3 in. Three different thicknesses of plywood were used to create the different obstacle heights: 0.25 in., 0.50 in., and 0.75 in. The pieces of plywood, up to the 0.75 in. high piece, were attached, in turn, to the surface of the asphalt with concrete anchor bolts. The obstacle heights above 0.75 in. were achieved by attaching additional pieces of plywood on top of the 0.75 in. piece with wood screws. This technique created obstacles with heights of; 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50, and 3.00 in.

4.2.3 Test Procedures.

The tests were designed to simulate the WIM process and to collect sufficient vehicle dynamic test data to validate the VEHDYN model. The tire pressures were maintained at 60 psi in the front four tires and 70 psi in the rear four tires. This was the vehicle manufacture's recommended highway tire inflation pressure. Prior to each series of tests the obstacle height of interest was secured in the test lane. Event reflectors were placed to indicate when each axle was on the center of the obstacle. The test vehicle was maneuvered to the beginning of the test course and positioned to be in line with the test obstacle. The vehicle's transmission was placed in the low-range position for the slow tests and in the high-range position for the fast tests. The driver removed his foot from the brake pedal and allowed the vehicle to

accelerate to the maximum idle speed. The speed the vehicle would reach prior to impacting the obstacle depended on the transmission gear selection. The lower-range gear produced an average speed of approximately 1.8 mph and the high-range gear produced an average speed of approximately 4.5 mph. The test driver would steer the vehicle so that both left and right wheels impacted the obstacle simultaneously. This technique minimized the roll of the vehicle. The vehicle then impacted the obstacle with each axle in succession. Only after crossing the obstacle and allowing the vehicle's suspension to dampen the dynamic effects did the driver use the vehicle's brakes.

The above test procedures were repeated three times for each obstacle height tested, and for each test speed. The vehicle was also tested in both the empty and loaded configuration.

4.3 DATA COLLECTED.

4.3.1 Drop Tests.

During the drop test only the chassis accelerometers and string pot channels were monitored. The data were digitized at 256 Hz. and captured on magnetic tape. The data were captured in the form of voltage outputs and using instrumentation calibration tests, transformed into engineering units through a post processor computer program.

4.3.2 Obstacle Tests.

The test vehicle was equipped with data signal telemetry capabilities operating at 400 Hz. analog. All 16 channels of instrumentation output was telemetried to the MSD Instrumentation Van. The van was equipped with a 16 channel analog to digital (A to D) processing board housed in a 386, 33 MHz personal computer. The instrumentation signal was also monitored and recorded on a 21 channel magnetic tape recorder. Both the A to D and tape recordings were accomplished without signal conditioning (data filtering). The A to D data were captured at 256 Hz. digital and stored in individual binary data files on a 250 megabyte hard disk drive. Each test file was given a unique name which identified it with a particular vehicle test. After each test the digitized data were plotted on the computer's monitor and visually inspected for

successful signal capture and clarity. If a data channel did not meet visual standards, the test was repeated before the next test sequence was conducted. The data were captured in the form of voltage outputs and, by using instrumentation calibration tests, transformed into engineering units through a post processor computer program.

SECTION 5

ANALYSIS OF TEST DATA

5.1 DATA REDUCTION TECHNIQUE.

An "in-house" written post processor computer program, T_HIS (Time HIStory), was used to analyze the test data. The program was designed to transform the raw instrumentation voltage output to engineering units and perform data analysis on all digitized channels within the same time frame of interest. The program options allow a variety of analysis techniques, including: signal conditioning with a four pole Butterworth filter; Fast Fourier Transformations (FFT) from the time domain to the frequency domain (Stearns, 1975); vehicle velocity calculations using the pipper encoded data; peak value searches through specified time windows; and locate and report event marker times. Table 5-1 shows a sample of the data reduction selections available.

Table 5-1. Data analysis selection in T_HIS program.

Select one of the following options
1) Filter Data
2) Calculate VEHDYN absorbed power
3) Calculate FFT
4) Phase shift or scale data
5) Move data on the "Y axis"
6) Find event markers
7) Move data on the "X axis"
8) Delete data on the "X axis"
9) Add, subtract, multiply, divide or copy channels
10) Find maximum
11) Calculate average pitch rate
12) Calculate the average
13) Calculate the root mean square
14) Calculate vehicle velocity by pips
15) Plot time history data
16) Create HP-GL data
17) Return to previous level

The T_HIS program was used to convert the instrumentation voltage output to engineering units, filter the digitized test data, perform peak value searches through specified time windows, calculate FFT's over specified time windows, perform peak amplitude searches through a specified frequency window, report maximum FFT amplitude and corresponding frequency through a specified time window, locate and report event marker times, and calculate the vehicle velocity through a specified time window.

5.2 DROP TEST.

5.2.1 Time History Data.

Drop tests were conducted to determine suspension characteristics and analyze vehicle natural frequencies. The data were measured in the form of time histories of the acceleration under the driver's seat and the rear center of the cargo area. These two locations were chosen to determine the suspension characteristics for the front pair and rear pair of suspensions. The vertical acceleration time history data presented in Figure 5-1 was filtered at 5 Hz and shows the trace of the acceleration under the driver's seat during the front

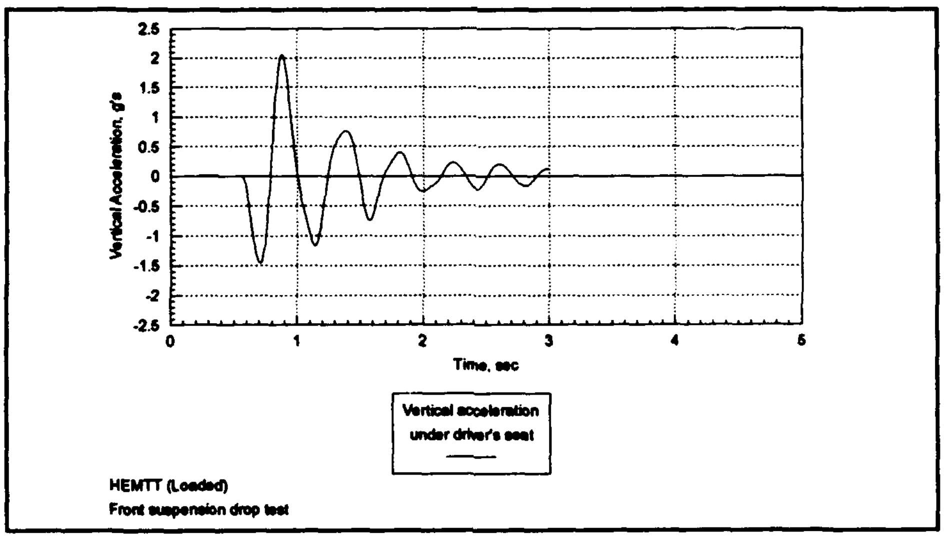

Figure 5-1. Vertical acceleration time history data from drop tests measured under the driver's seat.

walking beam drop test. As shown, the drop test measured a clean and smooth acceleration trace. The time history data presented in Figure 5-2 shows the rear walking beam drop test acceleration trace. This data was also filtered at 5 Hz. The data presents a clean and smooth acceleration trace. The damping affects of the suspension can be observed by the decay rate of the amplitude of the acceleration trace.

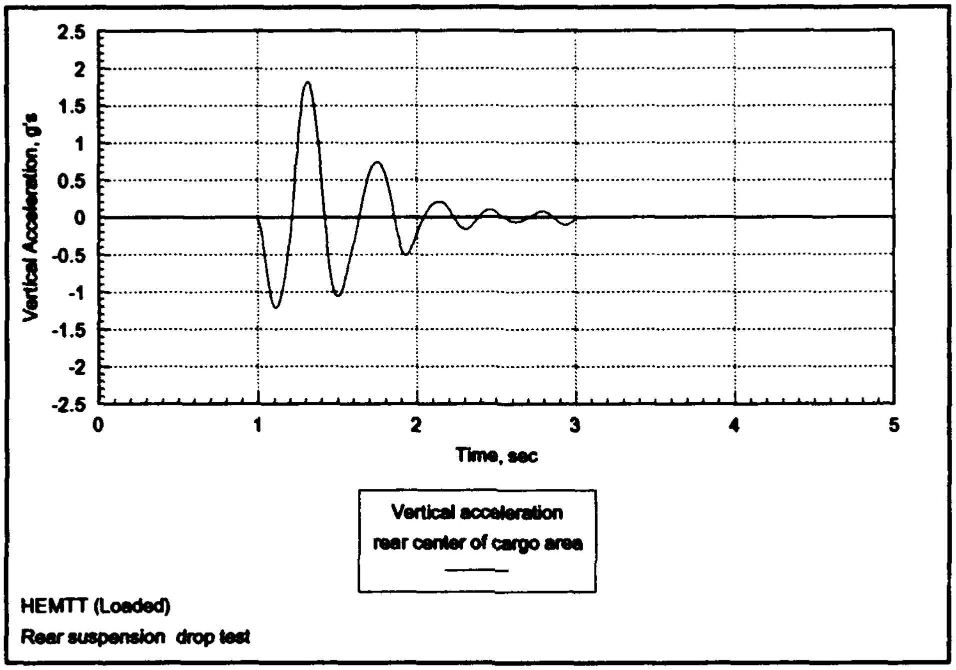

Figure 5-2. Vertical acceleration time history data from drop test measured at the rear center of the cargo area.

5.2.2 Frequency Analysis.

The data presented in Figure 5-1 and Figure 5-2 were analyzed in the frequency domain by using an FFT. The resultant FFT for the front walking beam drop test are presented in Figure 5-3. As shown, the maximum amplitude occurs at approximately 2.5 Hz. This peak represents the natural bounce frequency of the vehicle's chassis. Figure 5-4 presents the rear drop test and shows a similar peak at approximately 2.5 Hz. This also represents the natural bounce frequency of the vehicle's chassis. The natural frequency of the test vehicle's unsprung mass was not determined. But, the natural frequency of suspensions on wheeled

vehicles usually occur between 10 and 15 Hz (Jones, 1992). The HEMTT's suspension posses two natural frequencies. One is caused by the walking beam's vertical degree of freedom and the second by its rotational degree of freedom. The frequency analysis for the vehicle's suspensions are presented in following sections.

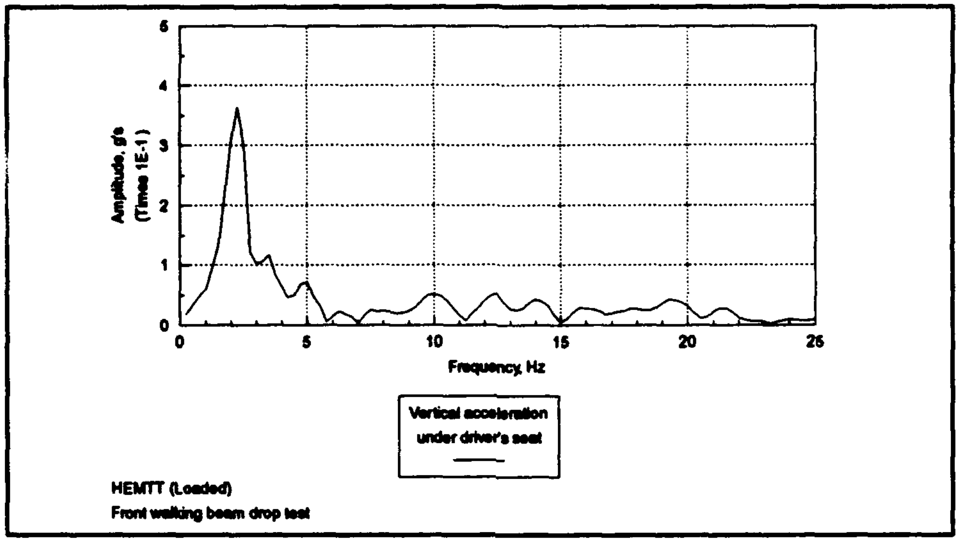

Figure 5-3. FFT of Figure 5-1.

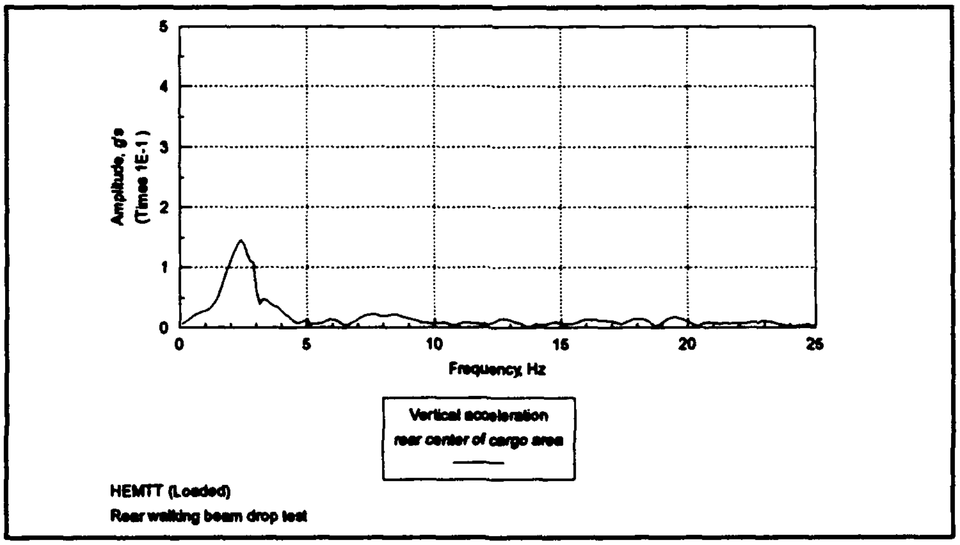

Figure 5-4. FFT of Figure 5-2.

5.3 OBSTACLE TEST.

5.3.1 Time History Analysis.

One of the objectives of the investigation was to determine the effects the WIM device would have on a vehicle during the weighing process. Therefore, the time period of interest was when one of the axles were being weighed. Once the axle left the WIM device, the chassis disturbance was not of interest for this study. Therefore, analysis techniques were focused on analyzing the vehicle dynamics during the critical time windows of the weighing process.

All time history test data were low pass filtered at 25 Hz before data analysis were conducted. This assured only frequencies which were caused by moving components of the vehicle were used during the analysis. Using the event markers, critical time windows were determined and analyzed. The HEMTT suspension design was such that two tires would be on the obstacle at once. As the front tire on a walking beam exited the obstacle the rear tire on the walking beam was impacting the obstacle. Therefore, the time window was set to analyze the vehicle dynamics from the time the front tire on a walking beam impacted the obstacle until the center of the rear tire on the walking beam exited the obstacle. Once the center of the rear tire on the walking beam exited the obstacle, the analysis was complete for that suspension. This was done to ensure the dynamic effects caused by the walking beam's rear tire exiting the obstacle was not part of the analysis.

From these time windows analysis were made on the time history data to determine the vehicle's response in terms of absolute peak values. To analyze the maximum peak value, the suspension event which created the maximum value was the one reported. That is, if the first suspension caused the largest vehicle pitch rate, then that absolute value was used in representing the pitch data. If on the same test the rear suspension caused the largest vertical acceleration at the c.g., then that absolute value was used in representing the acceleration data. This approach was used to analyze a worse case scenario.

Appendix D presents the test results in a tabular form. The table contains the data used to create the plots presented in the condensed data plots. The complete data base is presented.

This includes the data points which were not used in the data plots.

5.3.1.1 <u>Vehicle velocity.</u> The drive shaft pipper trace measured during testing was used to calculate the vehicle test velocity. Figure 5-5 shows the vehicle's velocity time history trace for a 1.00 in. high obstacle. Two points of interest must be noted. First is the amount of time it requires the vehicle to reach steady state velocity. Second is the amount of velocity fluctuation during the dynamic event. The vehicle must have ample room prior to the weighing process to reach a steady state velocity to minimize the amount of disturbance caused by the horizontal acceleration. If the vehicle was weighed prior to steady state velocity the front of the vehicle would pitch more during the dynamic event. This would induce error in the WIM measurements. The vehicle's velocity during the dynamic event fluctuates approximately 0.4 mph. This indicates the obstacle causes dynamic disturbance throughout the system. The amount will be shown in the following sections.

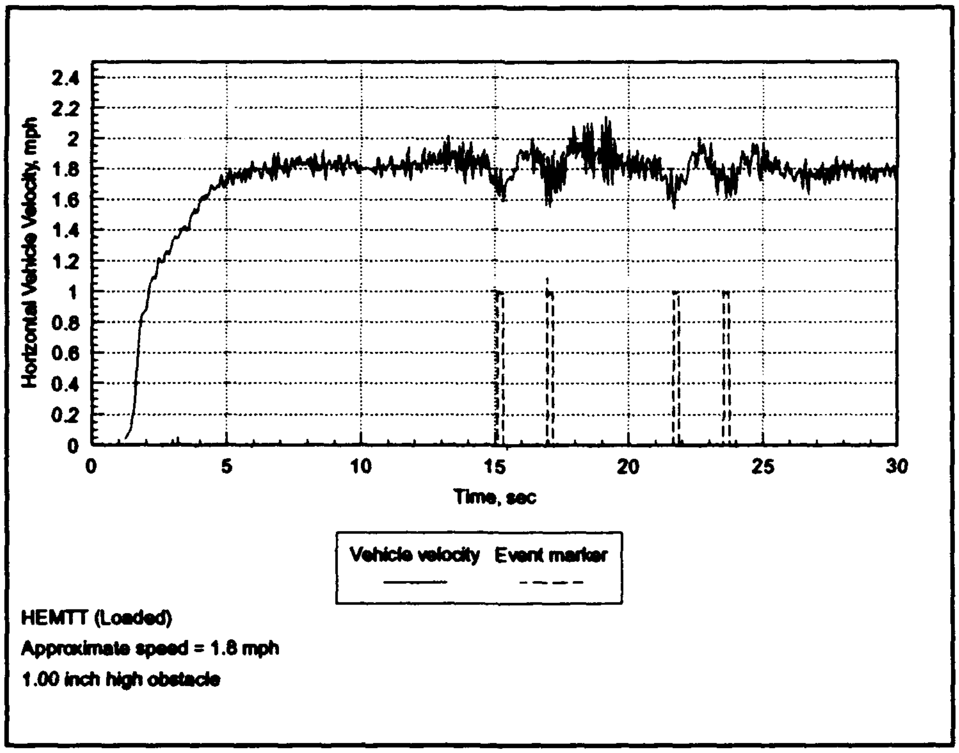

Figure 5-5. Velocity time history of vehicle crossing a 1.00 in. high obstacle.

5.3.1.2 <u>String pot data.</u> The string pot data were collected primarily for validating the VEHDYN model. But, it was also used to visually inspect the data and observe if the vehicle's suspension was disturbed by the obstacle. The data also showed any suspension disturbance during dynamic steady state prior to impacting the obstacle. Figure 5-6 shows a typical time history trace of a string pot output of the front left axle and the event marker trace as the vehicle traverses a 0.25 in. high obstacle. As shown, it is evident the vehicle impacts the 0.25 in. high obstacle at about 9 sec. with minimum suspension disturbance prior to the event. The trace drop from 4 to 7 sec was caused by steering adjustments the driver made so the vehicle would impact the obstacle as perpendicular to the obstacle as possible. The event marker indicates when each axle impacted the obstacle. These data are collected and stored in other channels.

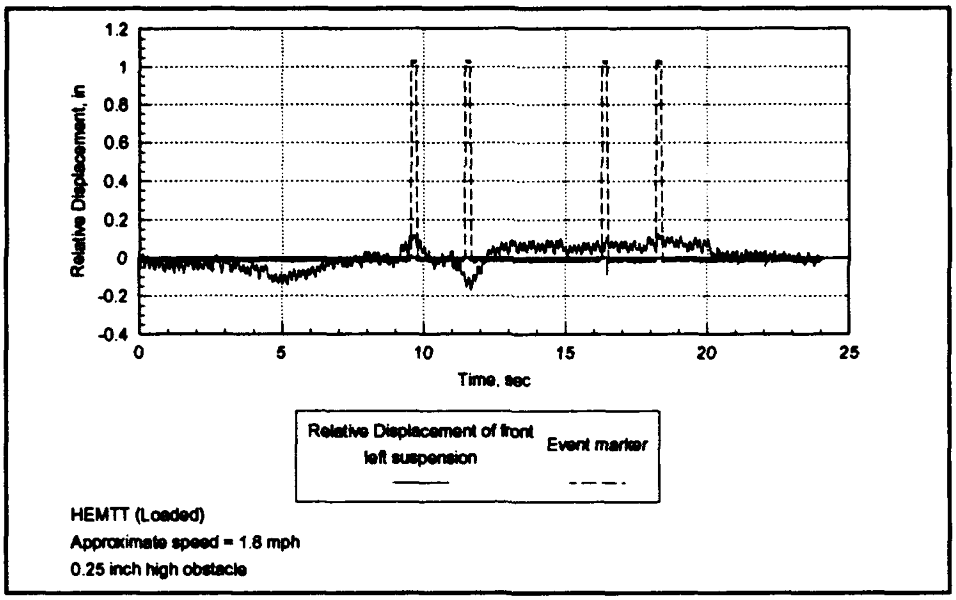

Figure 5-6. String pot displacement data for front left suspension crossing a 0.25 in. high obstacle.

Figure 5-7 shows the string pot time history of the front left suspension as the vehicle traverses a 1.00 in. high obstacle. The relative displacement of the chassis to the axle is much larger for this obstacle, but the trace is very similar to Figure 5-6. Again it can been seen in Figure 5-7 that just prior to the event the driver must adjust the vehicle steering to impact the obstacle straight on. Even though the steering adjustments are very slight they are

noticeable in the string pot data. From Figure 5-6 it can be seen that even a 0.25 in. high obstacle causes a small amount (0.175 in.) of suspension disturbance. The data analysis revealed that as the speed or obstacle height increased so did the amount of suspension displacement on all axles.

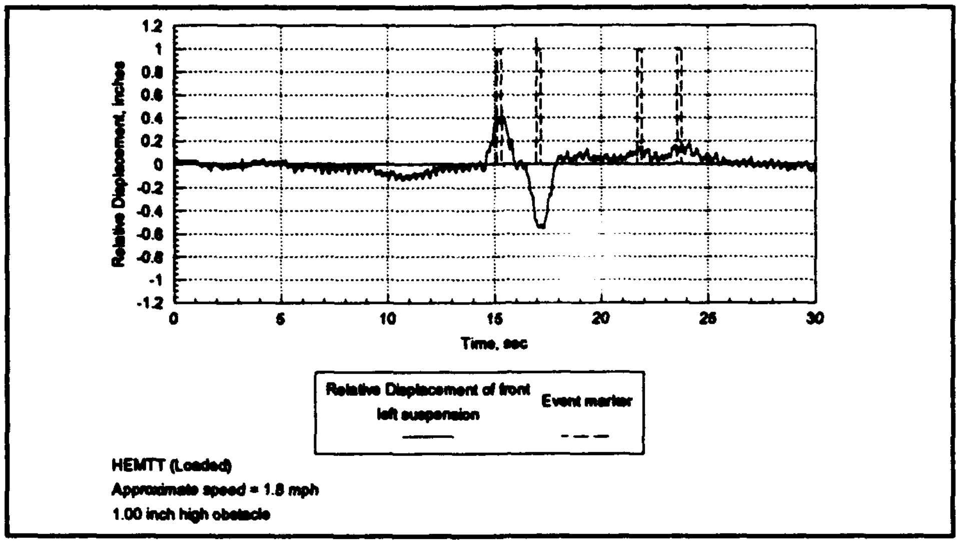

Figure 5-7. String pot displacement data for front left suspension crossing a 1.00 in. high obstacle.

5.3.1.3 <u>Pitch rate data.</u> The pitch rate time histories were used in absolute peak value analysis and a limited number of frequency analysis. Using the measured event marks for time references, peak value searches were conducted on the before obstacle-data and during-event data. Figure 5-8 shows a typical pitch rate time history trace for a 1.00 in. high obstacle. As shown, the event mark at 15 sec is when the vehicle's front axle is on the center of the obstacle. The following event marks are when the three trailing axles are on the center of the obstacle. The data trace shows that the obstacle causes significant chassis pitch when each axle impacts the obstacle.

Peak value searches were conducted on all tests and plotted in the form of absolute peak pitch rate versus obstacle height as shown in Figure 5-9. The plots made for the faster velocities and empty vehicle configuration are presented in Appendix A.

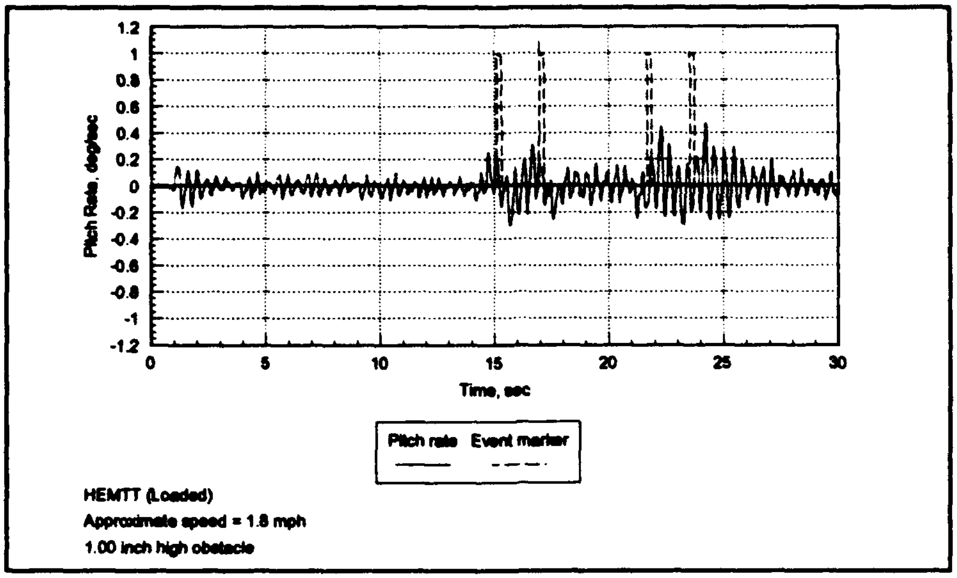

Figure 5-8. Pitch rate time history data as vehicle crosses a 1.00 in. high obstacle.

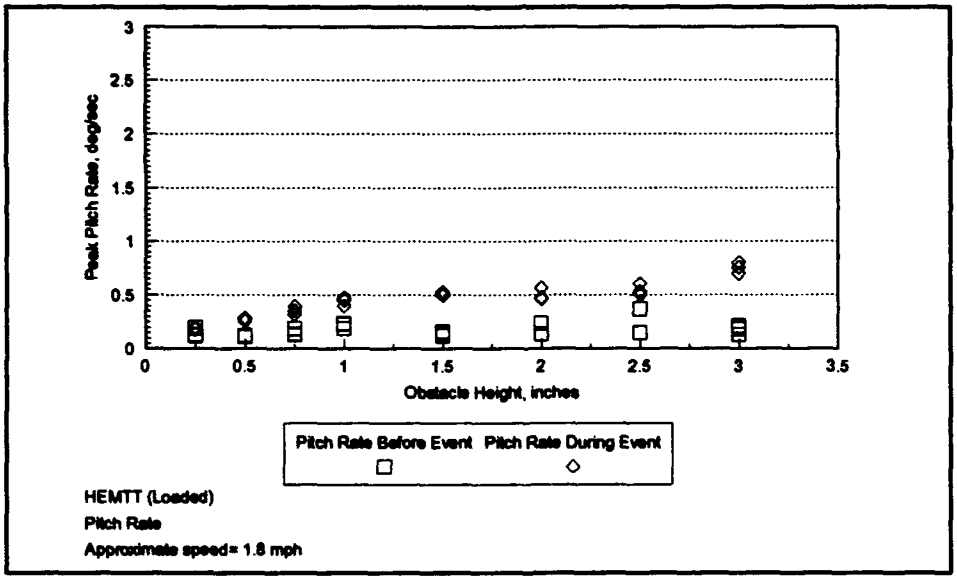

Figure 5-9. Peak pitch rate versus obstacle at 1.8 mph.

From the data shown in Figure 5-9 and Appendix A, it can be seen that as the obstacle height and speed increases so does the pitch rate. The magnitude of the event at each obstacle is small but, the amount even at the 0.5 in. obstacle is enough to cause pitch in the chassis.

This could induce loads in the WIM device at variance with the static loads. The plots also show the amount of steady state peak pitch rate. Which is the amount of pitch the vehicle experiences when traveling on smooth asphalt. The data shown can be attributed to imperfections of the vehicle and asphalt as a system and also to such imperfections as the out-of-round of the tires, or a tire out of balance. The reproducibility of the tests are also evident in the six data points plotted for the series of tests at each speed and obstacle height. The data presented follow the expected trend: as the obstacle height or speed increases so does the pitch for both the loaded and empty configurations.

5.3.1.4 **<u>Roll rate.</u>** The data analysis technique used on the roll rate data was identical to the process used on the pitch rate data. The test data presented in Figure 5-10 are from the same tests as Figure 5-8. As shown in Figure 5-10, the magnitude of the roll rate, when compared to the pitch rate, is higher during dynamic steady state but less during the dynamic event. This could be attributed to the imperfections of the system as stated previously. The expected trend would be for the steady state pitch and roll effects to be similar.

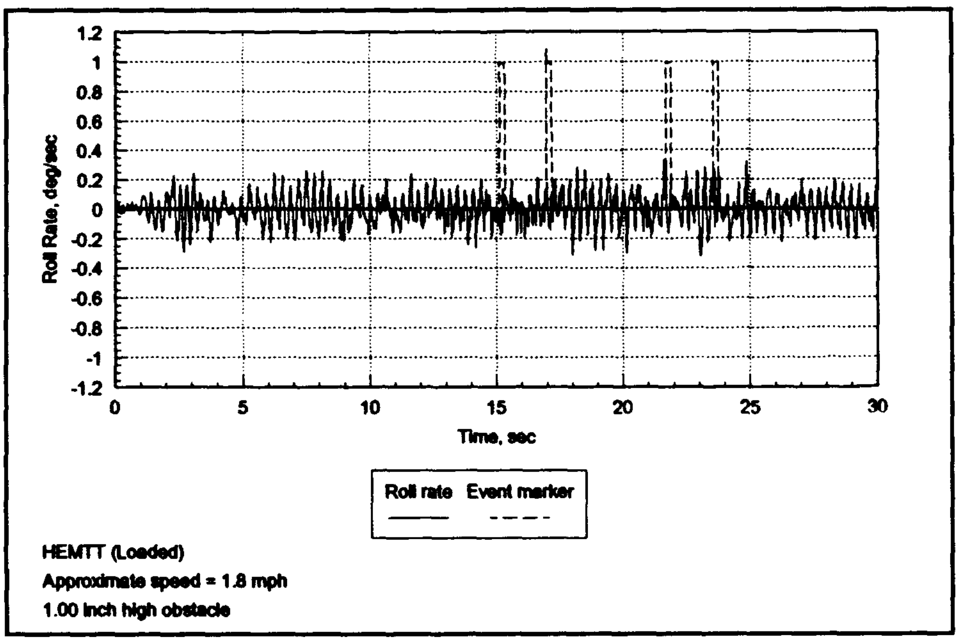

Figure 5-10. Roll rate time history data as vehicle crosses a 1.00 in. high obstacle.

The data in Figure 5-11 presents the peak roll rate for dynamic steady state and during the dynamic event for each test. The data shows a higher steady state roll rate than the pitch rate for the same test. It also shows an overall lower roll rate during the event then the pitch. However, the resulting roll is sufficient to warrant concern that it may not be possible to exclude the roll as a contributing factor to the dynamic disturbance of the vehicle. These data suggests that the obstacle causes dynamic response in more than just two dimensions.

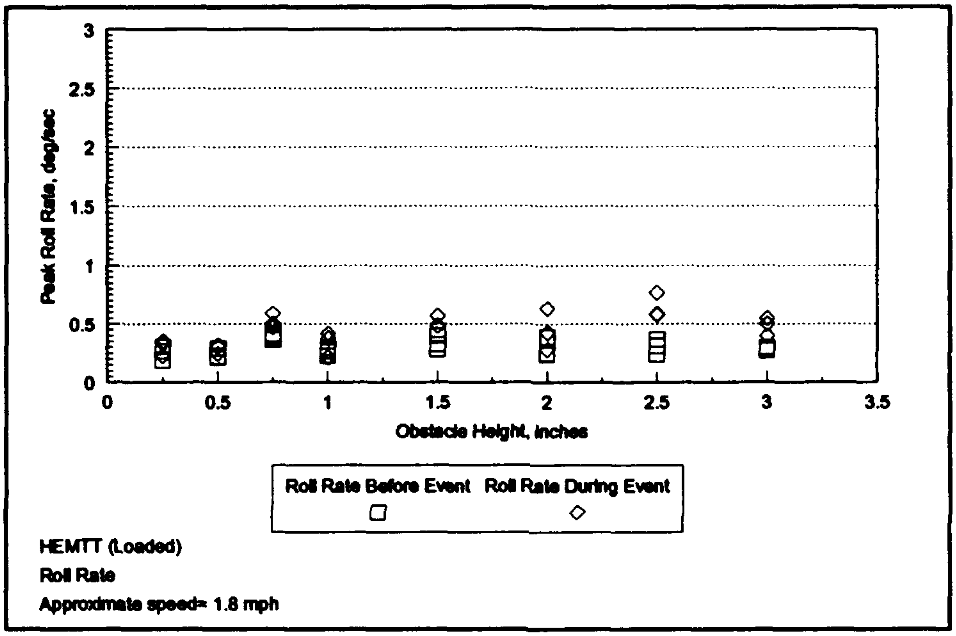

Figure 5-11. Roll rate versus obstacle height at 1.8 mph.

Peak value searches were conducted on all tests and plotted in the form of absolute peak roll rate versus obstacle height as shown in Figure 5-11. The plots made for the faster velocities and empty vehicle configuration are presented in Appendix A.

5.3.1.5 Axle acceleration. The acceleration time history presented in Figure 5-12 represents the front left axle during the same test as previously presented. The data shows the dynamic steady state acceleration and the dynamic event. The dynamic event is not as noticeable and the axle accelerations are small due to the slow test velocities.

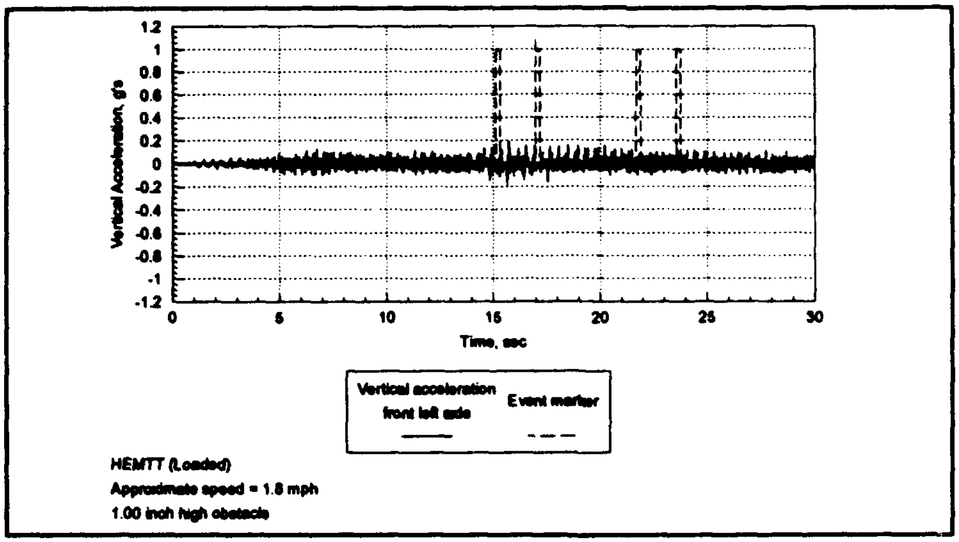

Figure 5-12. Vertical acceleration time history data of the front left axle crossing a 1.00 in. high obstacle.

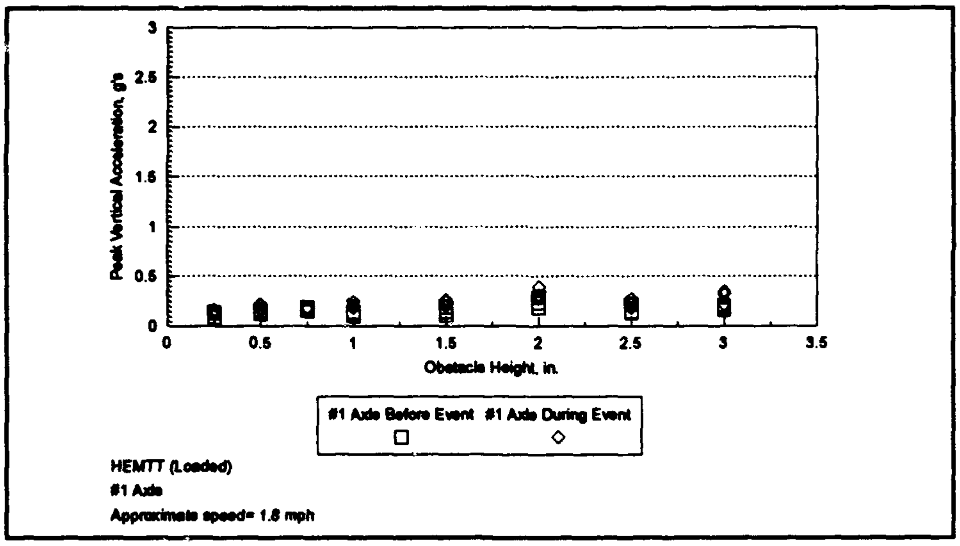

Figure 5-13. Peak vertical acceleration of #1 axle versus obstacle height.

Peak value searches were conducted on all tests and plotted in the form of absolute peak vertical acceleration versus obstacle height. Figure 5-13 shows the relative difference between the steady state vertical acceleration peaks and the dynamic event peaks for each obstacle height tested for the front left side axle with the vehicle in the loaded configuration at

low velocities. The magnitude of the vertical accelerations are very small because of the height of the obstacles and the velocity at which they were impacted. The differences between the steady state dynamics and the dynamic events are not as large as seen in the pitch or roll analysis, but the significance is in the amount of force these accelerations represent. Appendix A shows the differences for the other axles and test configurations. It is apparent that the rear axles generate slightly higher accelerations. This is due to the stiffer springs and dampers in the rear suspension. If the suspensions were able to transfer sufficient forces from the impacting of the obstacle to the chassis, the WIM accuracy would be affected.

5.3.1.6 <u>Chassis acceleration.</u> The most important of the data measurements were the chassis acceleration. The magnitudes of these measurements were critical in determining the allowable WIM device height. The same tests shown in the previous figures were used to present a typical chassis acceleration time history. As shown in Figure 5-14, the amount of vertical acceleration at the vehicle's c.g. was very small. The largest amount of vertical acceleration occurs during the rear axle impact. This is seen at the third event mark. This also correlates with the pitch and suspension data.

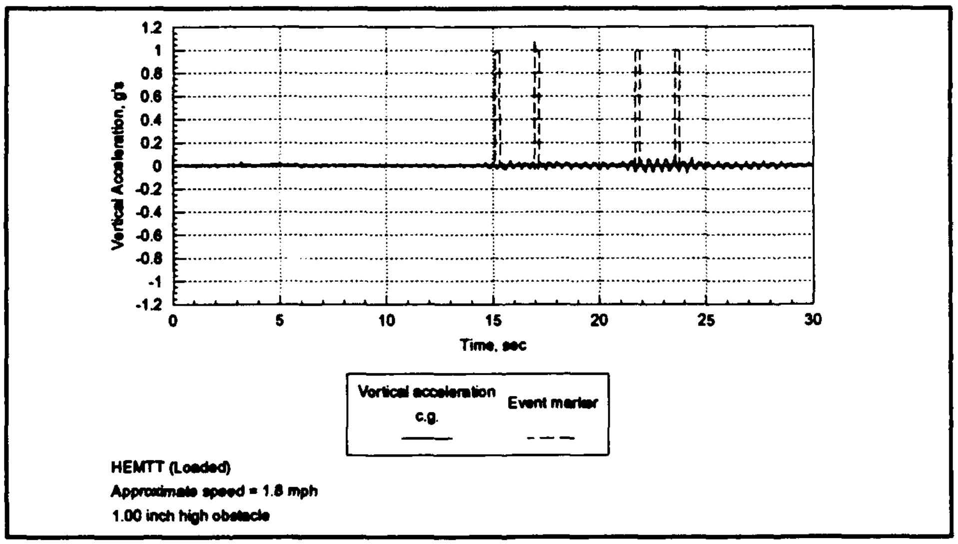

Figure 5-14. Vertical acceleration time history data of vehicle's c.g. crossing a 1.00 in. high obstacle.

The magnitude of the acceleration is put in perspective if the force acting on or away from the ground by the front and rear axles are calculated. The mass of the vehicle was 60,106-lb divided by 32.2 ft/sec^2, which equals 1,867 slugs. Newton's force equation states; force (F) equals mass (m) times acceleration (a); F=ma. If the vehicle's total mass is 1,867 slugs, and for simplicity we assume the front suspension causes half as much vertical acceleration at the c.g. as the rear suspension, as shown in Figure 5-14, when they encounter the WIM device. Then from Figure 5-15, the rear suspension causes a vertical acceleration at the c.g. of 0.09 g's for a 1.00 in. high obstacle. Then the front suspension would cause a vertical acceleration at the c.g. equal to 0.045 g's acting on half the mass, which is 934 slugs. Therefore, the change in the total vertical force under all the axles would increase or decrease by;
$F=(934\ \text{slugs})(0.045\ \text{g's})(32.2\ ft/sec^2/g) + (934\ \text{slugs})(0.09\ \text{g's})(32.2\ ft/sec^2/g) = 1353\text{-lb} + 2707\text{-lb} = 4060\text{-lb}$. This means a total of 4060-lb was in movement during the weighing process. That equals 7 % of the vehicle's total weight. If the vertical acceleration for the 0.25 in. high obstacle, presented in Figure 5-15, is used, the total force is 1804-lb. This represents 3% of the vehicle's weight. This is also the amount which is in motion when the vehicle is in a steady state condition. These crude calculations reveal the impact of small vertical accelerations on the weighing process.

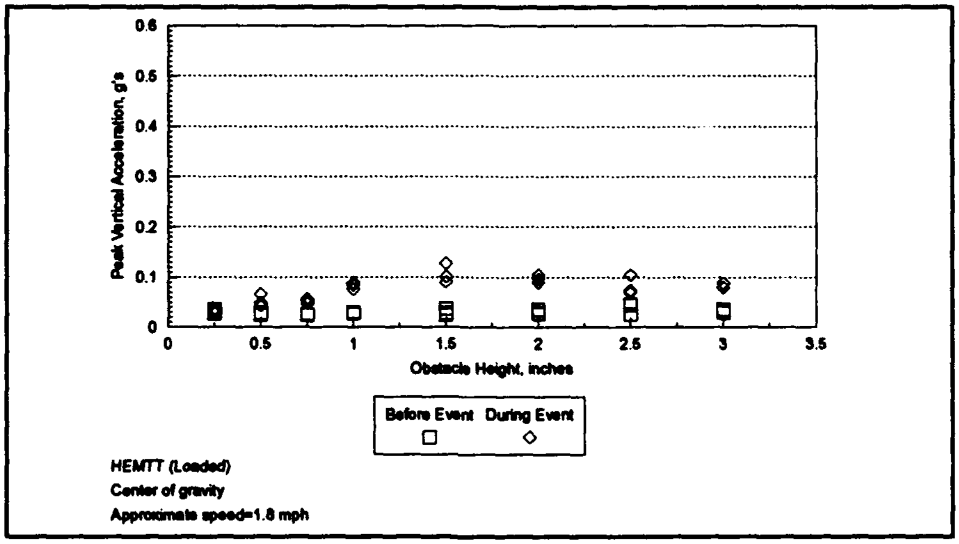

Figure 5-15. Peak vertical acceleration of the vehicle's c.g. versus obstacle height.

Figure 5-15 shows the peak vertical accelerations of the vehicle's c.g. for the different obstacle heights. As the obstacle height increases, so does the amount of vertical acceleration. The amount of vertical acceleration appears to flatten at the 1.5 in. obstacle height. This indicates the suspension is able to absorb the affects of the higher obstacles. The faster velocities and empty vehicle configuration are presented in Appendix A.

5.3.2 Frequency Analysis.

To analyze the frequency data and present it in a condensed form, time windows of the total dynamic event were used. Since the time response was being transformed into a frequency analysis, it was not necessary to analyze discrete windows as in the time domain. The data used in the frequency analysis was sampled at 256 Hz specifically for the FFT analysis. The FFT used in the analysis required a discrete data base which numbered to 2^y, with y any integer. This included data base sizes like; 64, 128, 256, etc. In order to assure the test data met this criteria, mirroring techniques were used when necessary. The mirroring technique used consisted of extending the data base by using the following algorithm:
$n_{j+1}=n_{i-1}$ where: j=500,501,502,....512; i=500,499,498,.....,488. The data were analyzed in the unfiltered format and presented in the form of frequencies at maximum amplitudes versus obstacle height and the corresponding amplitudes versus obstacle height. This analysis technique was used for all obstacle testing.

The vehicle's dominant frequencies were analyzed to determine frequency trends. A few of the trends found were predictable. As shown in the drop test frequency analysis, wheeled vehicle systems are normally constructed with natural frequencies of the chassis in the range of 1 to 3 Hz. This construction technique is common practice to prevent vibration in the range of 4 to 6 Hz, which is damaging to human internal organs. The results of these construction techniques produce suspensions that tend to have natural frequencies in the range of 10 to 15 Hz. Therefore vehicle frequencies which are outside these ranges need to be explored for explanations. The following analysis presents the vehicle's frequencies that follow predictable trends along with frequencies that are outside the typical ranges. The following analysis also offers possible explanations for those frequencies that reside outside the typical ranges.
It should be noted that in order to present the data in a consistent format, the dynamic steady

state data use a different Y axis scale than the dynamic event data. If both data groups were to use the same scale some data would not be visible.

5.3.2.1 Pitch rate frequencies. The FFT of the steady state pitch rate time history data presented in Figure 5-16 shows the dominant frequency to be the same as the natural frequency of the vehicle, between 2 and 3 Hz. The data also show pitch occurring between 0 and 1 Hz and between 5 and 7 Hz. Figure 5-17 presents the FFT of the pitch rate during the

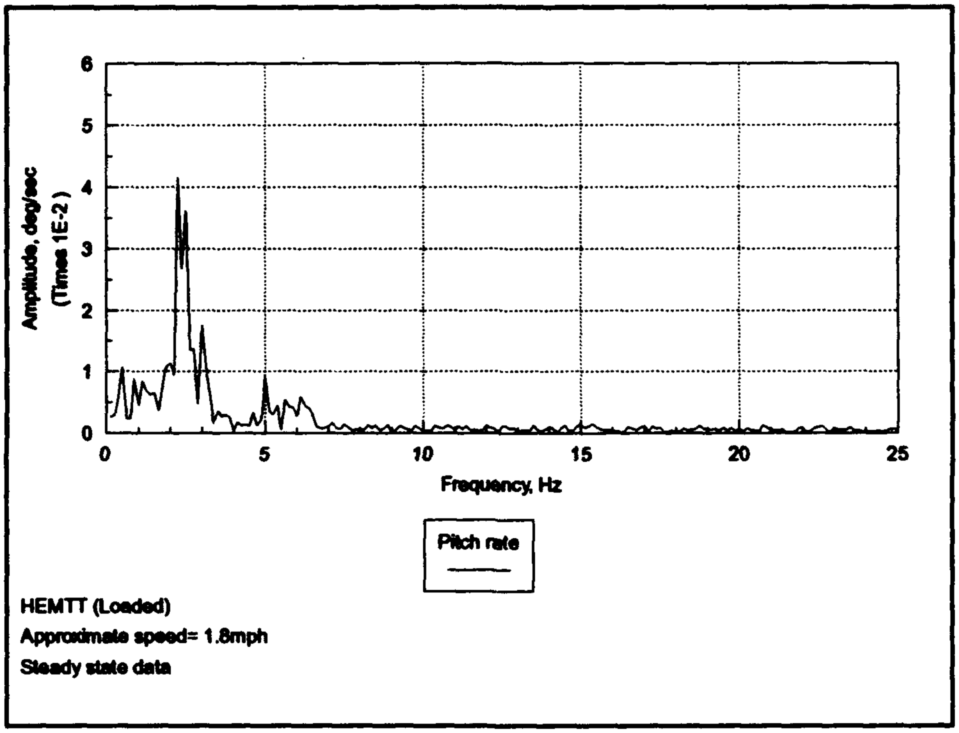

Figure 5-16. FFT of vehicle's pitch rate during steady state dynamics.

dynamic event. As shown the dynamic event causes the steady state frequencies to become more evident. The pitch at 0 to 1 Hz is believed to be caused by the tires being *out-of-round* and possibly out-of-balance. This frequency is only seen in the pitch and roll rate data, which indicates the acceleration at this frequency was not large enough to be detected by the accelerometers. If the tires were out-of-round or balance the results would be a very low and slow oscillation. This would also be consistent with the vehicle's low velocity.

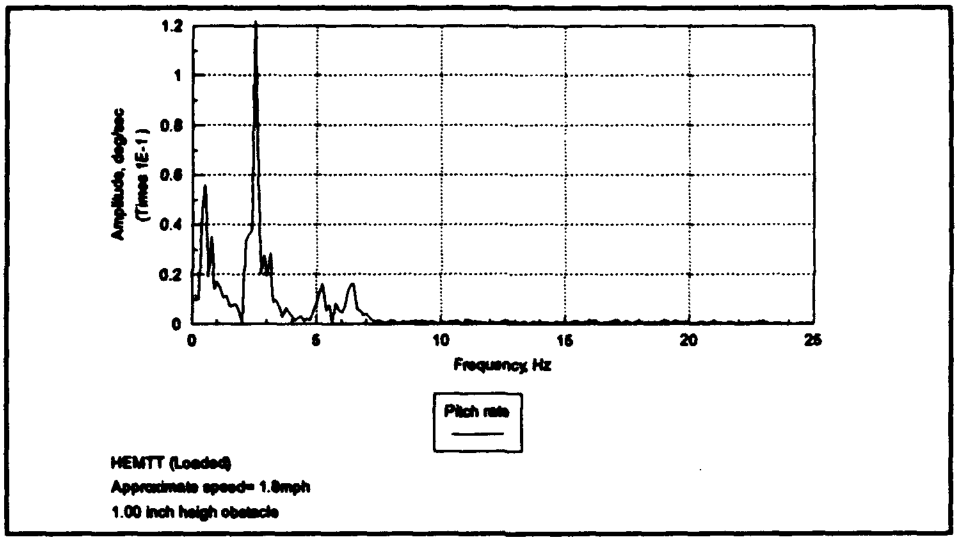

Figure 5-17. FFT of vehicle's pitch rate during dynamic event crossing a 1.00 in. high obstacle.

5.3.2.2 <u>Roll rate frequencies.</u> The FFT of the before-event roll rate in Figure 5-18 reveals roll occurring at 0 to 1 Hz, 3 to 4 Hz, a small spike at 6 Hz and at 12 to 13 Hz. The following analysis shows some of these frequencies in other measured quantities, but the roll rate is the only quantity which contains all these frequencies.

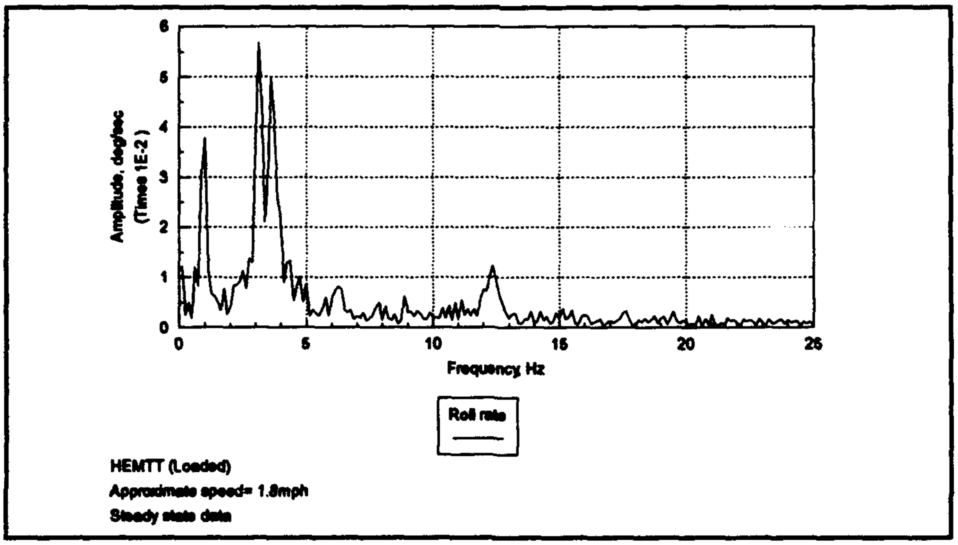

Figure 5-18. FFT of vehicle's roll rate during steady state dynamics.

The roll rate of the vehicle is the easiest to influence because it has the smallest mass moment of inertia. The roll rate occurring at 0 to 1 Hz and 3 to 4 Hz is also consistent with the explanation offered in the pitch rate analysis. The frequencies occurring at 5 to 7 Hz are believed to be caused by the rotational degree of freedom in the walking beam suspension. The frequencies occurring in the range of 12 to 13 Hz are attributed the vertical degree of freedom in the suspension. These frequencies are also present in the suspension analysis. The FFT of the dynamic event is shown in Figure 5-19. This data show the same frequencies as the steady state data, but the range of frequencies are more pronounced.

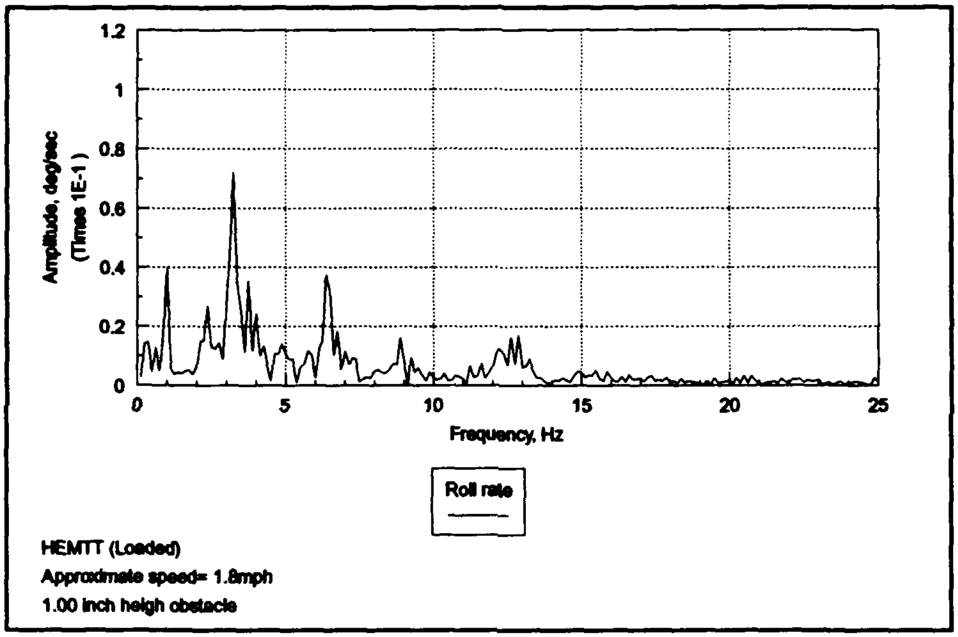

Figure 5-19. FFT of vehicle's roll rate during dynamic event crossing a 1.00 in. high obstacle.

5.3.2.3 Axle frequencies. The front left axle has accelerations occurring at 2 to 3 Hz, 6 to 7 Hz, and 12 to 13 Hz during steady state operation, as shown in Figure 5-20. The 2 to 3 Hz is associated with the natural frequency of the vehicle's tires; the natural frequency of radial tires is usually in this range. Therefore, the higher frequencies are produced by the suspension system. The 6 to 7 Hz is probably caused by the rotation of the walking beam and the 12 to 13 Hz by the vertical motion of the suspension. The dynamic event only enhances these frequencies, as shown in Figure 5-21.

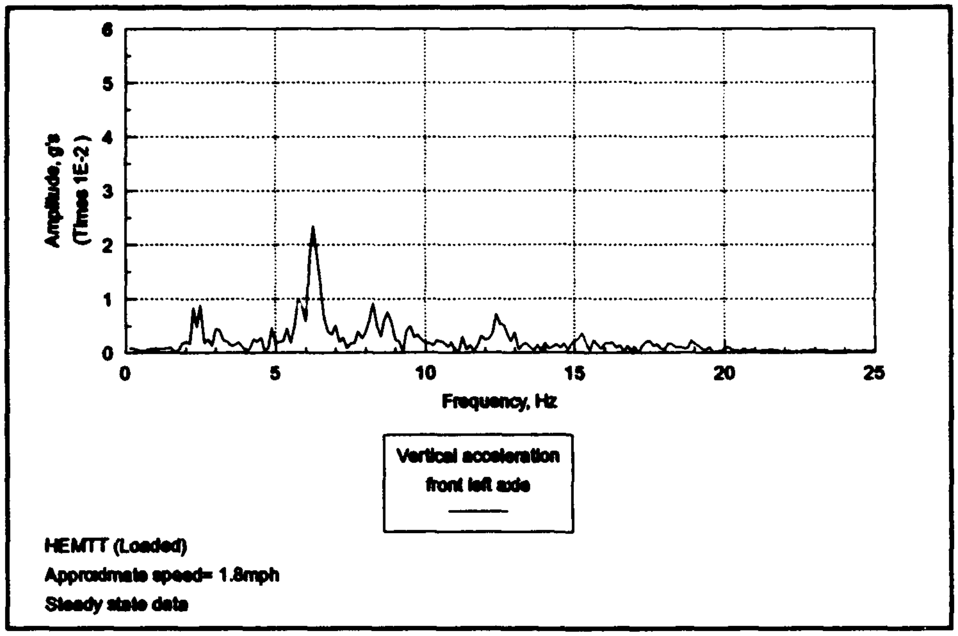

Figure 5-20. FFT of vehicle's front left axle acceleration during steady state dynamics.

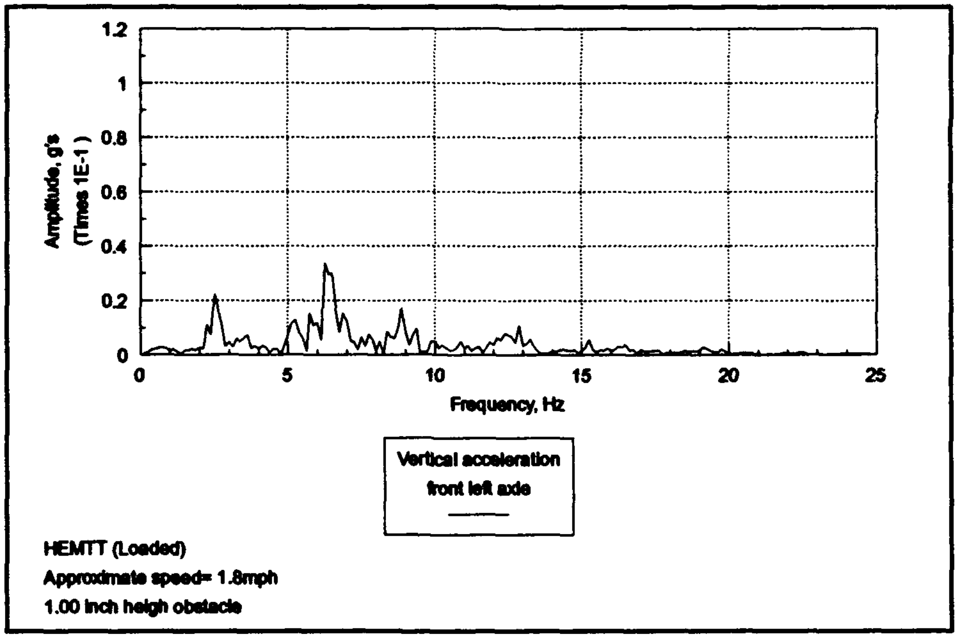

Figure 5-21. FFT of front left axle acceleration during dynamic event crossing a 1.00 in. high obstacle.

The rear left suspension shows higher amplitudes for the higher frequencies during the steady state operations, shown in Figure 5-22. The acceleration which was occurring at 2 to 3 Hz in the front axle is not present in the rear axle until the dynamic event, seen in Figure 5-23. This is also consistent with the stiffness difference of the front and rear suspensions. The front suspension is softer, which would allow lower frequency accelerations to affect its' performance during steady state operations. The stiffer rear suspension would prevent these steady state accelerations from affecting its performance until a larger dynamic event occurred.

Both suspensions exhibit accelerations occurring at similar frequencies. These accelerations are the result of the walking beam suspension's design. The rotational degree of freedom responds slower than the vertical degree of freedom creating the 5 to 7 Hz frequency. The higher 12 to 13 Hz frequency is assigned to the vertical motion since most independent suspensions posses a natural frequency in this range.

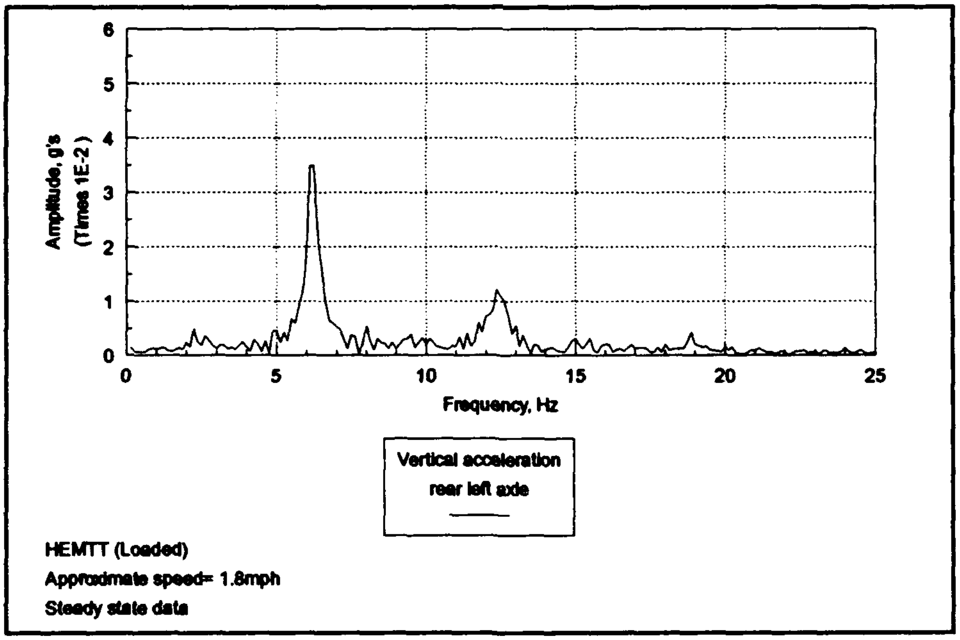

Figure 5-22. FFT of rear left axle acceleration during steady state dynamics.

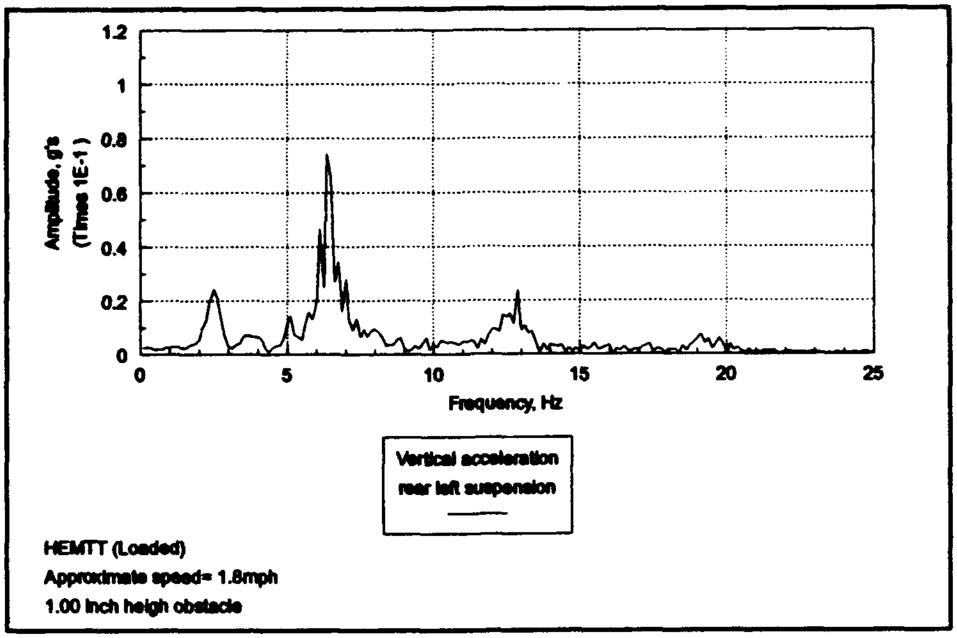

Figure 5-23. FFT of rear left axle accelerations during dynamic event crossing a 1.00 in. high obstacle.

5.3.2.4 <u>Chassis frequencies.</u> The frequency response of the chassis is the same as shown in the drop test analysis. The vertical acceleration measurements taken under the driver's seat show accelerations occurring at frequencies similar to those of the pitch and roll rate, except for the low 0 to 1 Hz frequencies. This would support the explanations offered on the lower 0 to 1 Hz frequencies. Since the instrumentation was off-set from the lateral center line, the accelerometer should have measured the roll motion. Therefore, the 0 to 1 Hz roll motion must have been occurring at a rate too slow to measure with accelerometers. The data presented in Figure 5-24 shows the frequencies at which the accelerations occur under the driver's seat during steady state operations. The frequencies during the dynamic event are the same as those in Figure 5-24.

The accelerations occurring at the vehicle's c.g. during steady state operations are the same as those seen in the drop tests. Figure 5-25 shows the acceleration frequencies during steady state operation. The only frequency present is the natural frequency of the vehicle. The frequency analysis of the c.g. during the dynamic event is shown in Figure 5-26. As

shown, the vehicle's natural frequency is the only frequency present before and during the dynamic event.

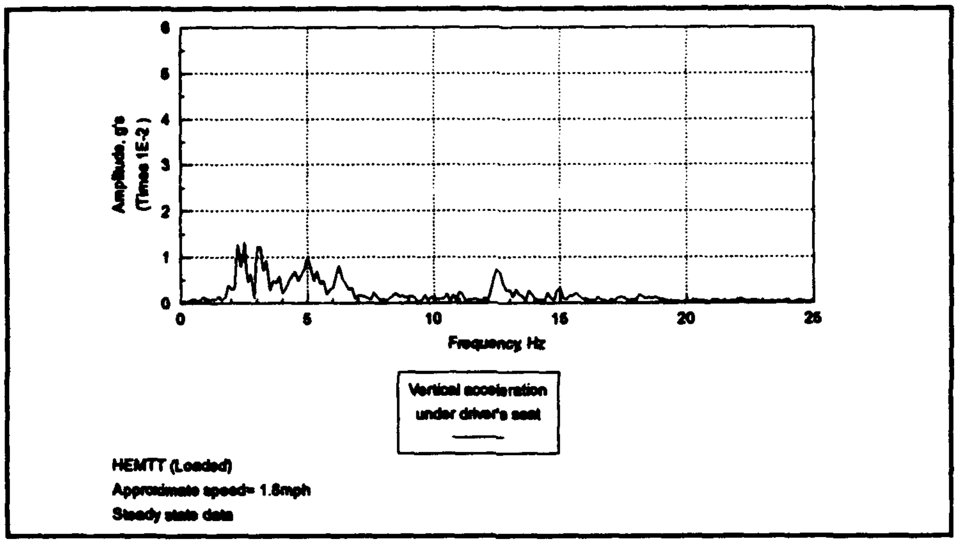

Figure 5-24. FFT of accelerations under the driver's seat during steady state dynamics.

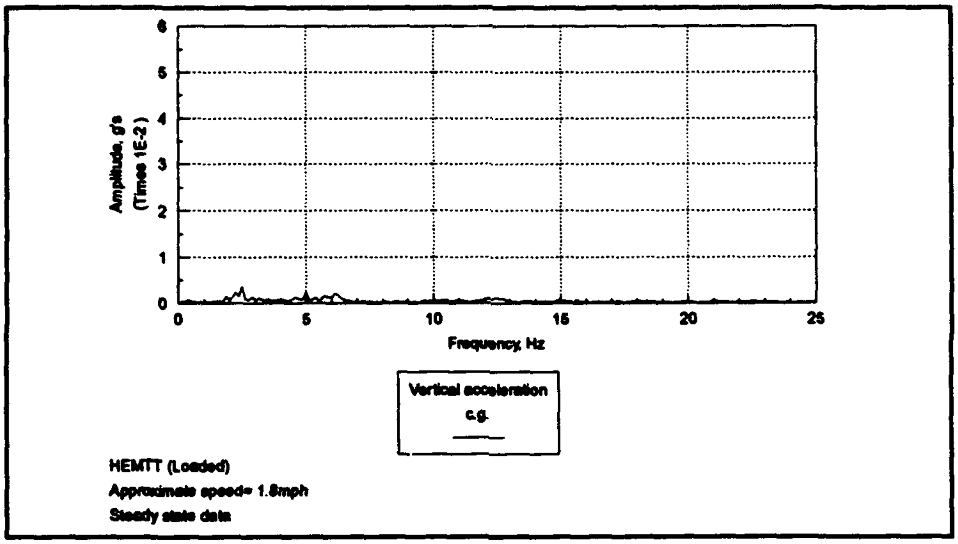

Figure 5-25. FFT of accelerations at the vehicle's c.g. during steady state dynamics.

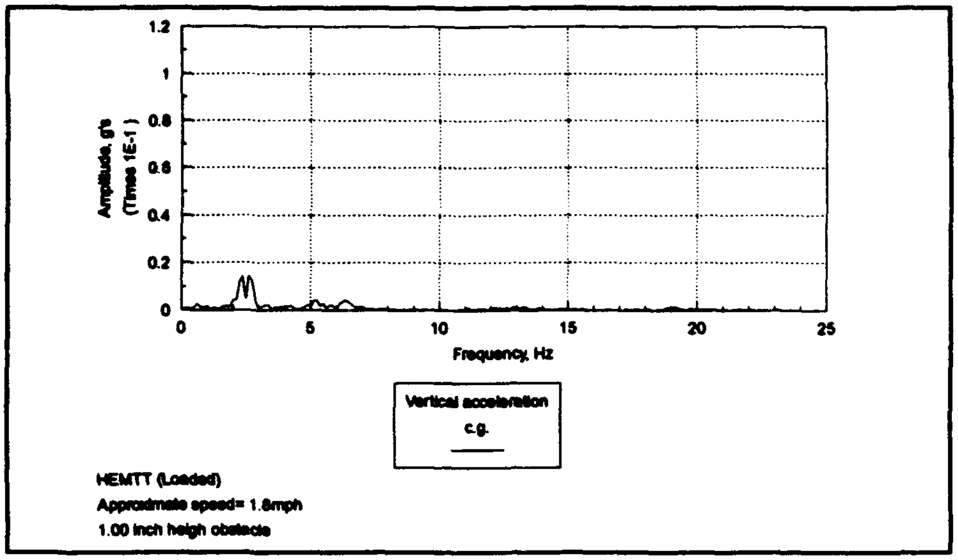

Figure 5-26. FFT of accelerations at the vehicle's c.g. during dynamic event crossing a 1.00 in. high obstacle.

5.3.3 Condensed frequency plots.

Appendix B presents plots made using the frequency which caused the maximum amplitude. These frequencies are plotted versus each obstacle height tested. These plots were generated to determine the dominant frequencies of the vehicle. Points were calculated using unfiltered data from each test conducted. As shown throughout all the testing three dominant frequencies appear with no apparent pattern. The frequencies are those shown previously; 2 to 3 Hz, 6 to 7 Hz, and 12 to 15 Hz. These are the three natural frequencies of the system, the chassis possessing the 2 to 3 Hz frequency and the suspension possessing the 6 to 7 and 12 to 15 Hz frequencies.

The data presented in Appendix C represent the amplitudes at which the corresponding frequencies were found. The data are presented in the form of maximum amplitude versus obstacle height. These data were plotted in order to determine if trends existed in the magnitude of the dominant frequency. The data show better consistency than that in Appendix B, but again are unpredictable. Some of the plots yield noticeable trends, but again they are not consistent throughout the system.

SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS.

The data analysis revealed critical quantities and areas for vehicle dynamic analysis, including the acceleration of an off set from the lateral center line, the roll rate, pitch rate, and acceleration of the c.g. With these measurements, the effects of low profile linear obstacles on different vehicles could be determined.

The instrumentation type and data reduction were suitable and successful for model validation and vehicle analysis. The selection and implementation of the instrumentation were done to enhance data collection and ensure high quality measurements. The testing techniques were simplistic and very operational. The overall success of the program is attributed to these areas.

The data presented indicate that entrance distances prior to a dynamic event should be long enough for the vehicle to achieve a steady state velocity in order to minimize dynamic disturbance. The vehicle is affected by steady state operation and it does cause sufficient chassis disturbance to alter the accuracy of a WIM device. The data are also conclusive in showing that obstacles higher than 0.25 in. induce chassis movement. The analysis revealed the vehicle's natural frequencies. These frequencies would induce error in the WIM process and would have to be accounted for in the final output.

6.2 RECOMMENDATIONS.

The test program was designed to answer specific questions pertaining to WIM devices and to collect model validation data. The data collection technique used is suitable for a variety of analyses, such as the dynamic effects of modifying the tire design, tire size, tire pressure, spring rates, and damper rates. The data collection technique also appears to hold possibilities for vehicle identification. Each class of vehicle has different frequency characteristics which are similar to those shown in this report. By measuring the dynamic

characteristics of a family of trucks, it would be possible to generate frequency categories into which most trucks would fall. From this research, algorithms could then be written which would adjust the WIM device's output to account for the effects of the vehicle's natural frequencies.

SECTION 7
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APPENDIX A

PEAK VALUE PLOTS FOR STEADY STATE DYNAMICS AND DYNAMIC EVENT DATA

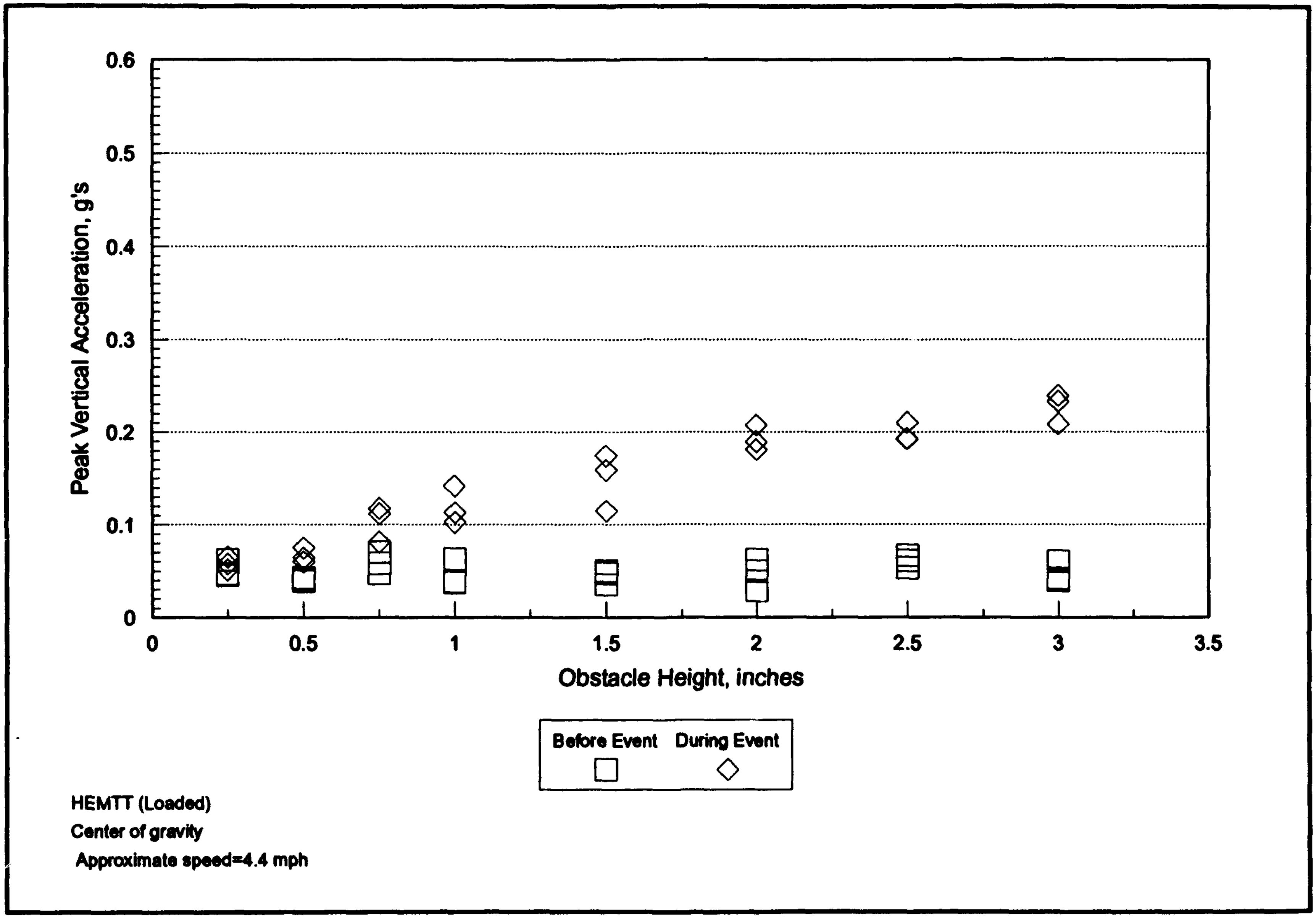

Chart A-1. Peak vertical g's versus obstacle height for c.g. at 1.8 mph (loaded vehicle).

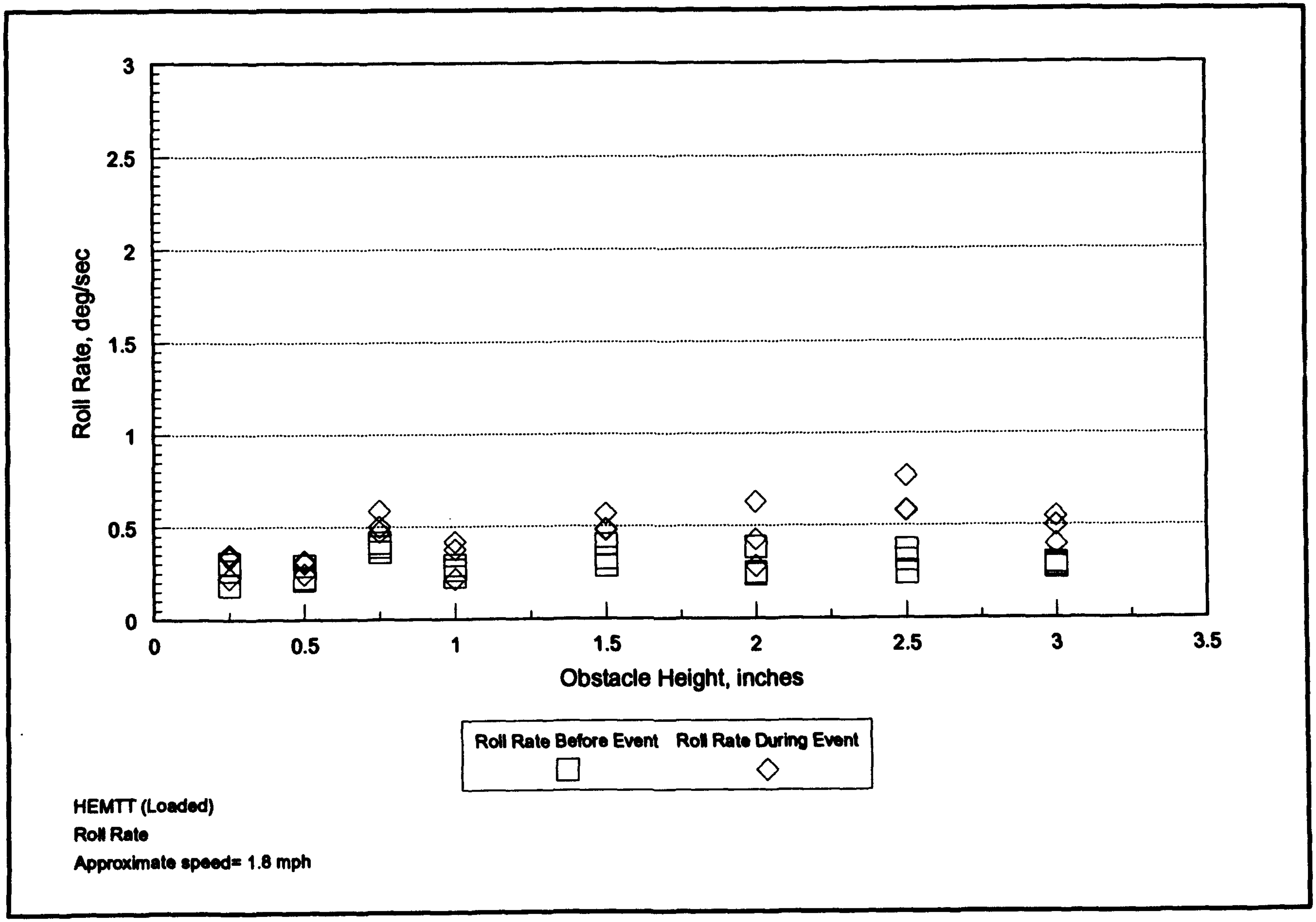

Chart A-2. Peak pitch rate versus obstacle height for at 1.8 mph (loaded vehicle).

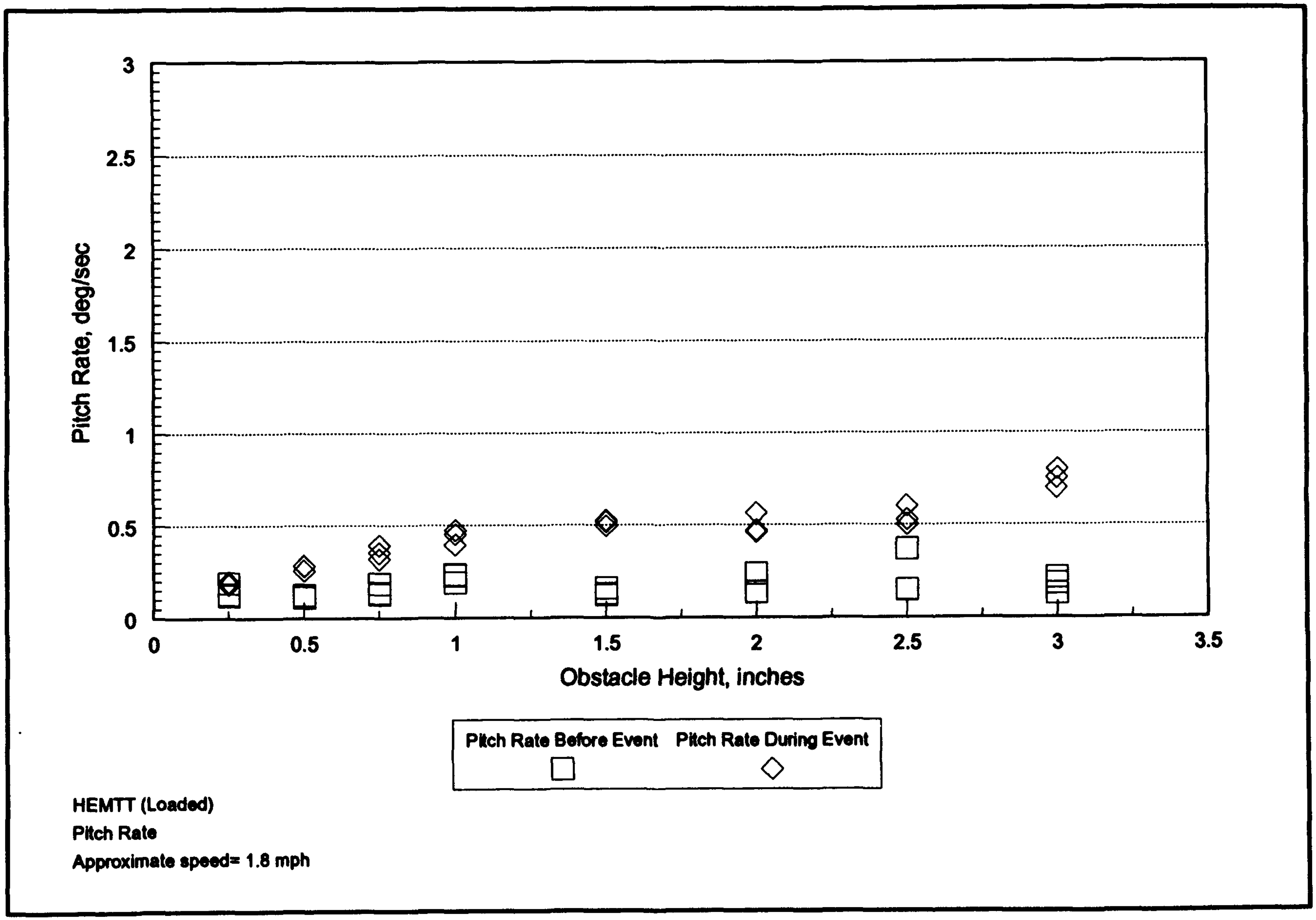

Chart A-3. Peak roll rate versus obstacle height at 1.8 mph (loaded vehicle).

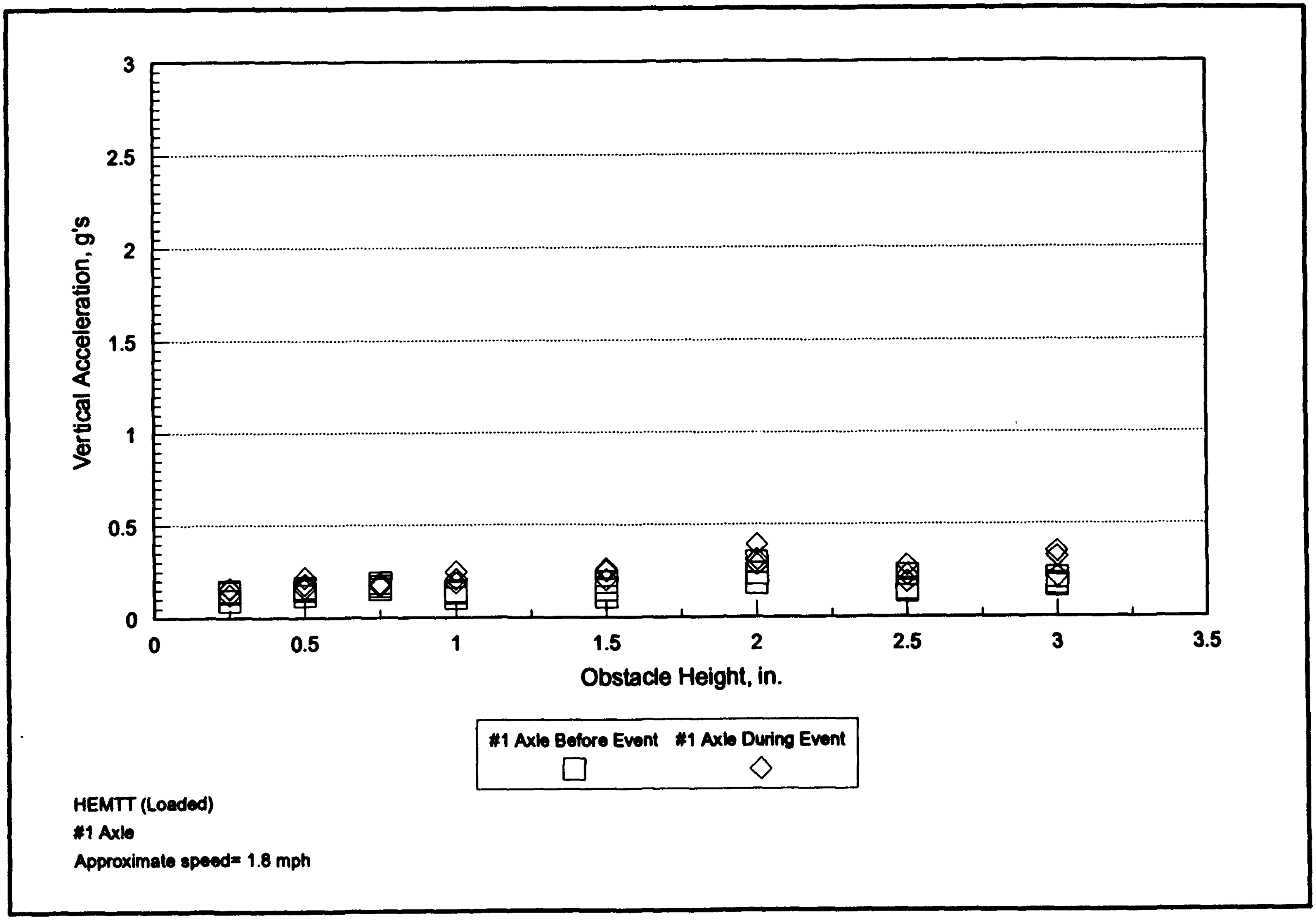

Chart A-4. Peak vertical g's versus obstacle height for axle #1 at 1.8 mph (loaded vehicle).

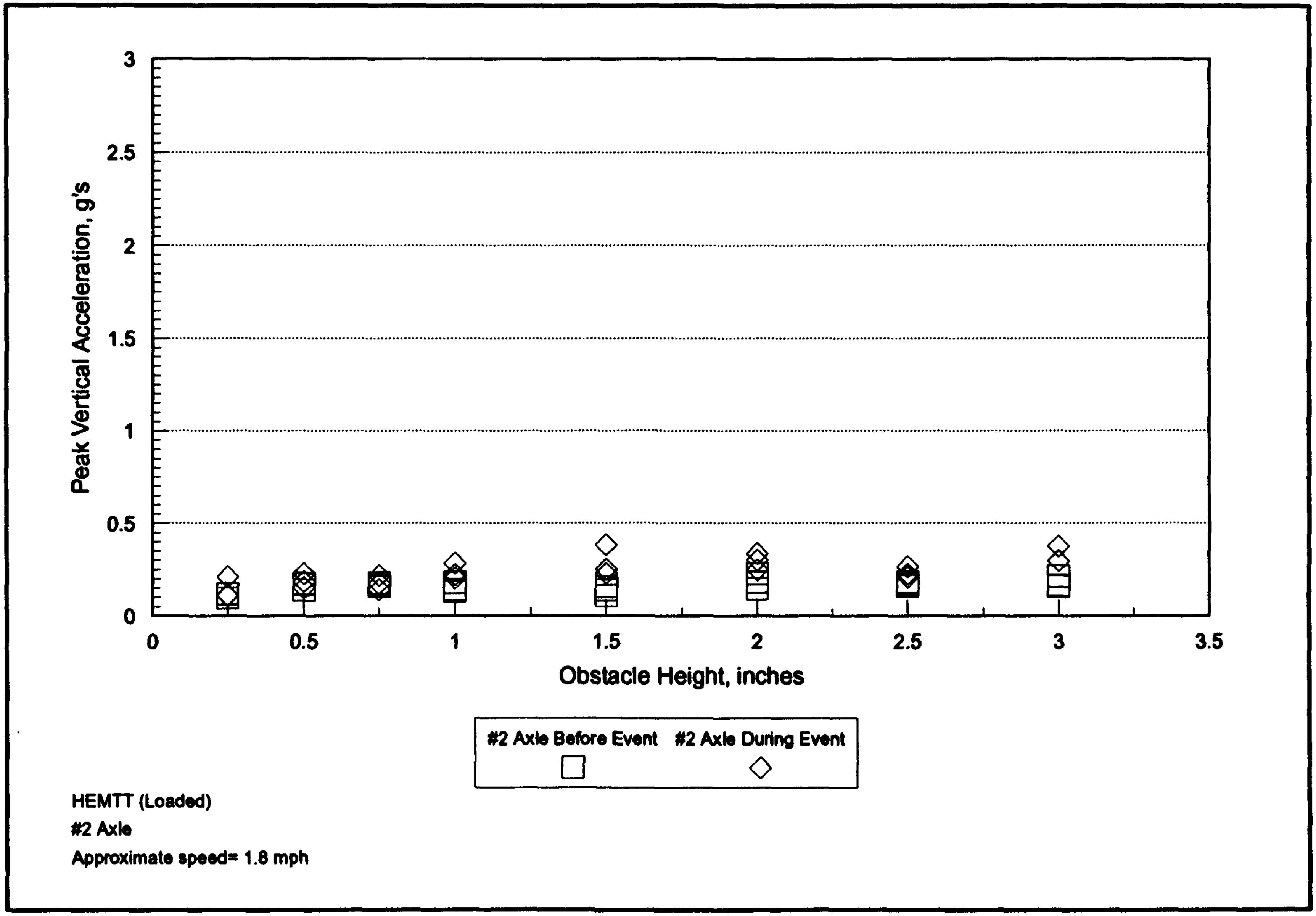

Chart A-5. Peak vertical g's versus obstacle height for axle #2 at 1.8 mph (loaded vehicle).

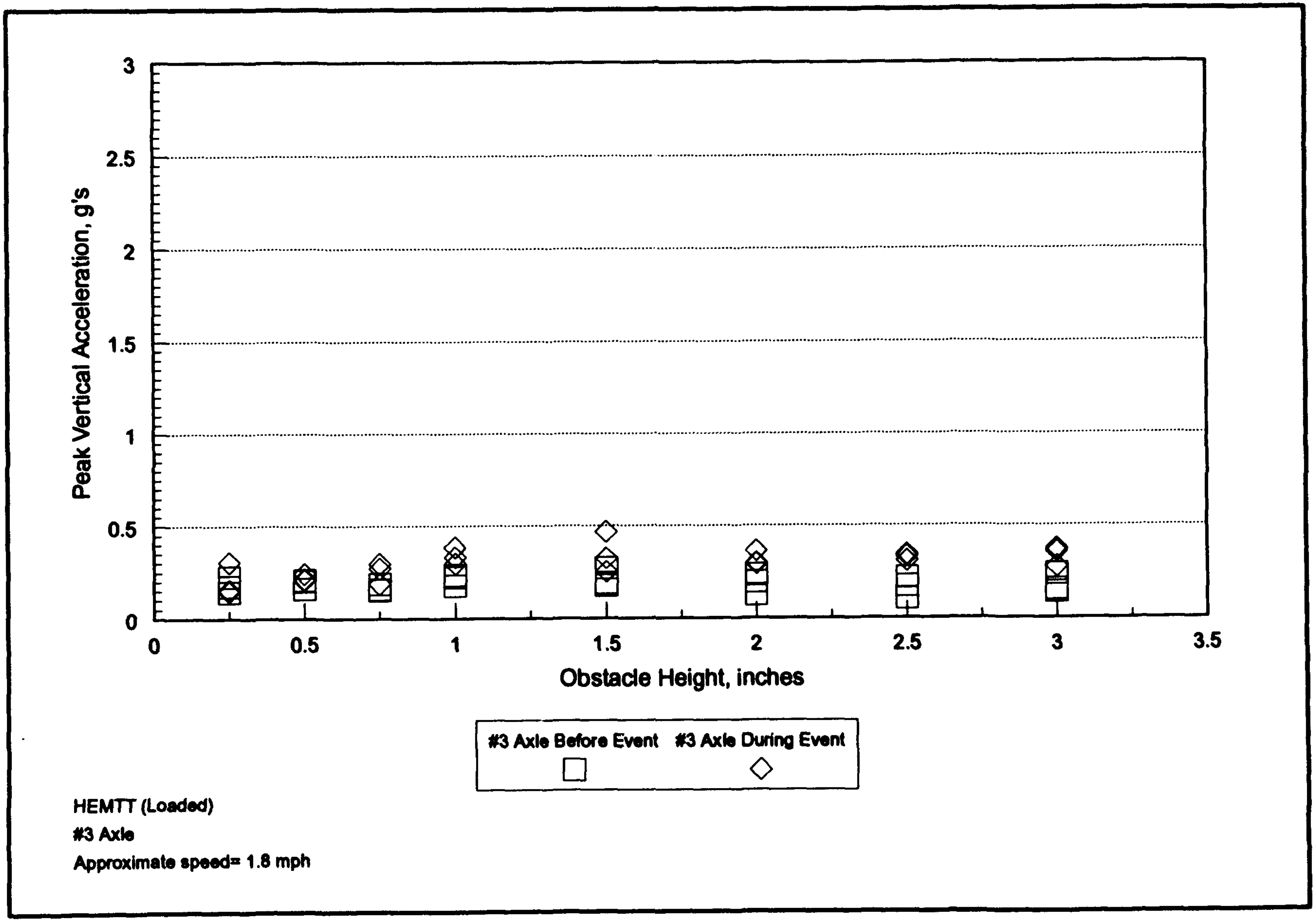

Chart A-6. Peak vertical g's versus obstacle height for axle #3 at 1.8 mph (loaded vehicle).

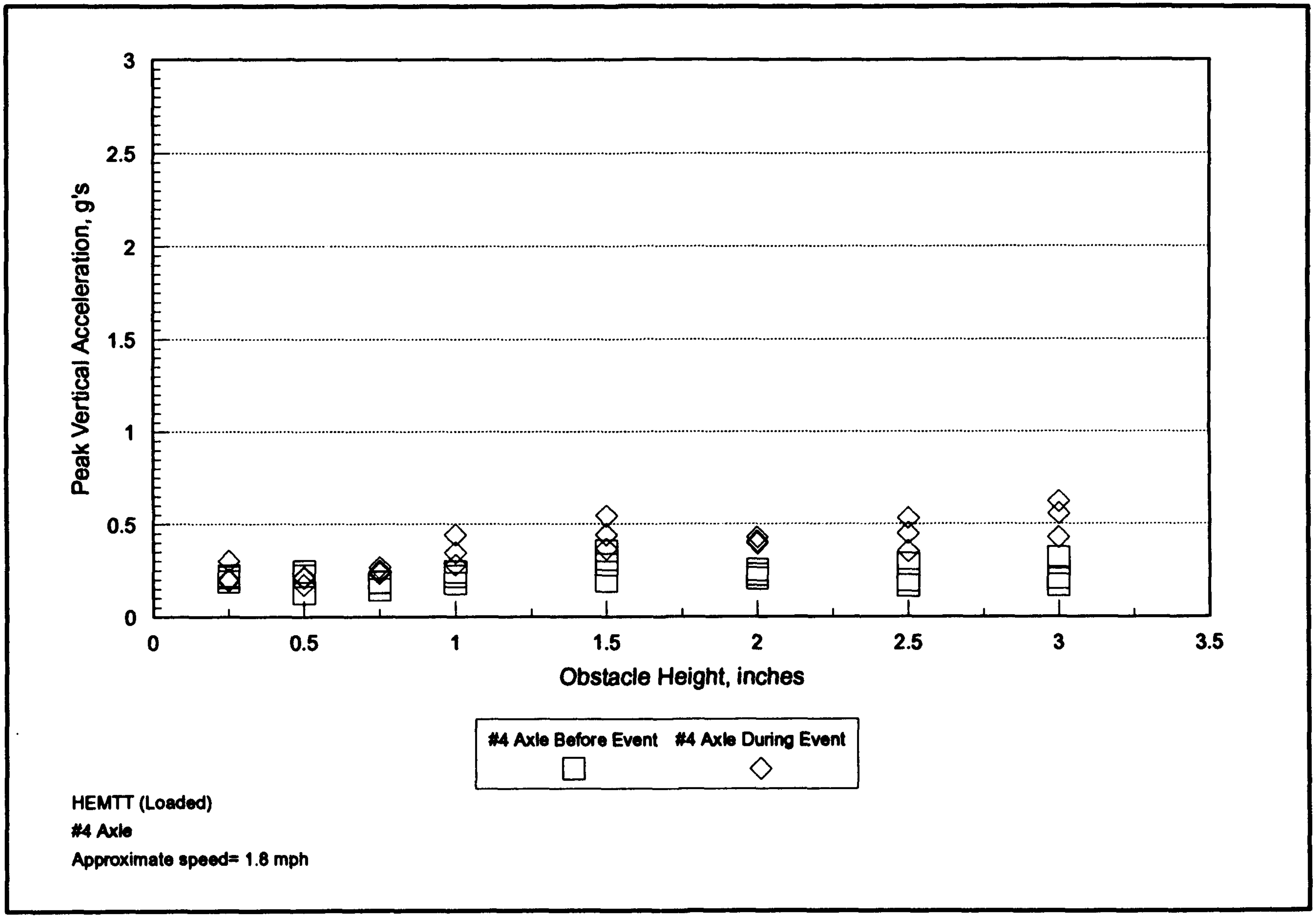

Chart A-7. Peak vertical g's versus obstacle height for axle #4 at 1.8 mph (loaded vehicle).

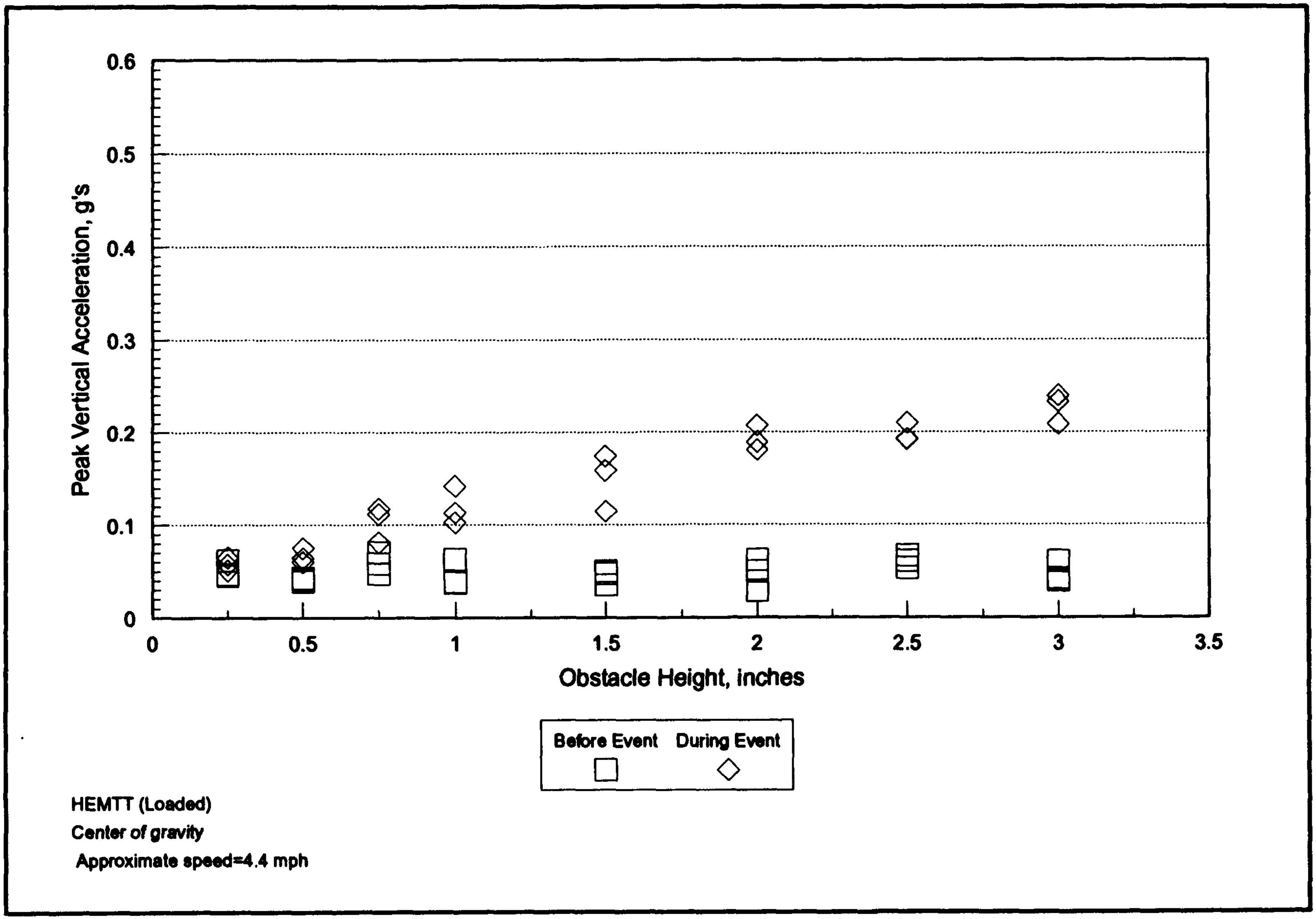

Chart A-8. Peak vertical g's versus obstacle height for c.g. at 4.4 mph (loaded vehicle).

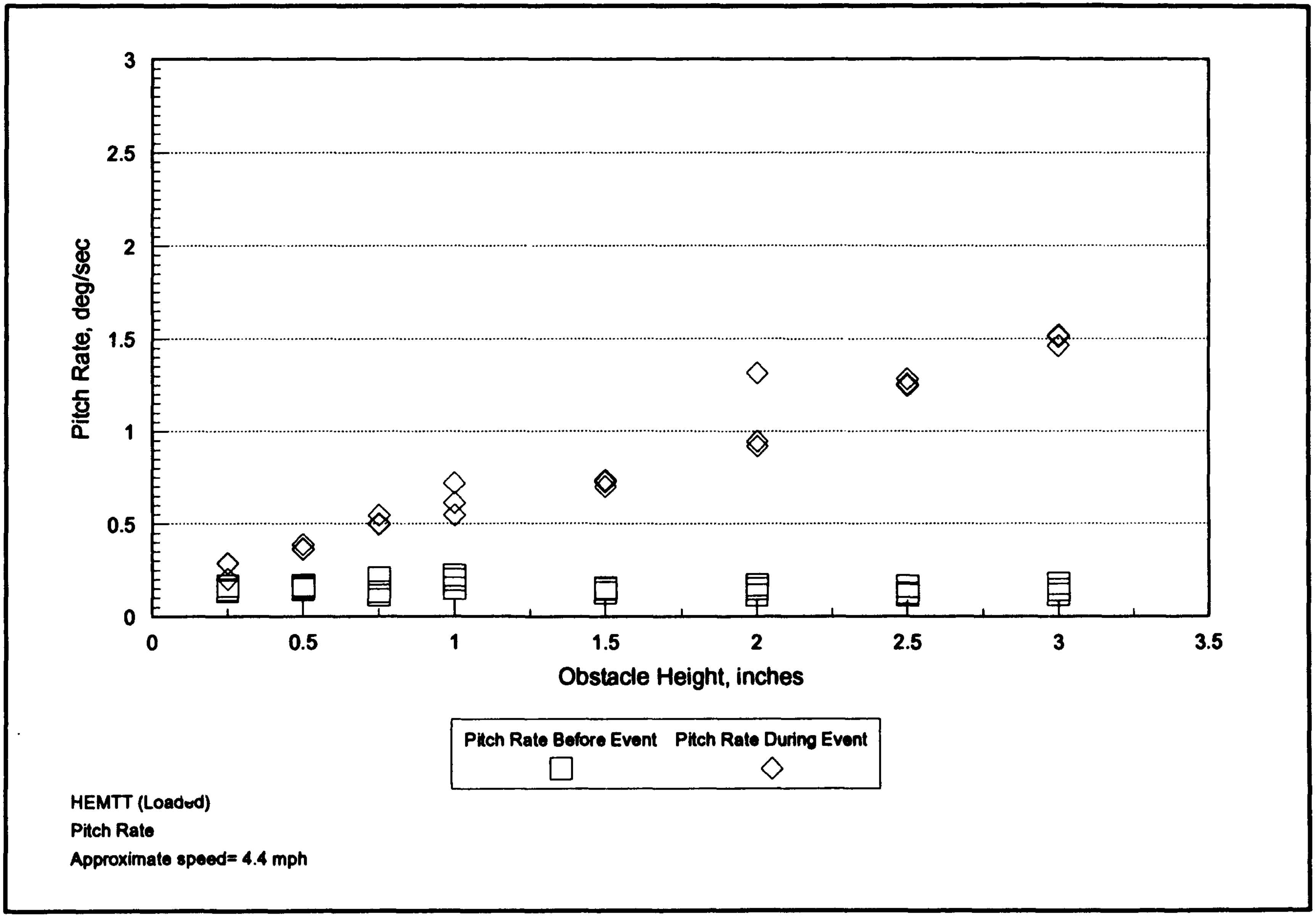

Chart A-9. Peak pitch rate versus obstacle height at 4.4 mph (loaded vehicle).

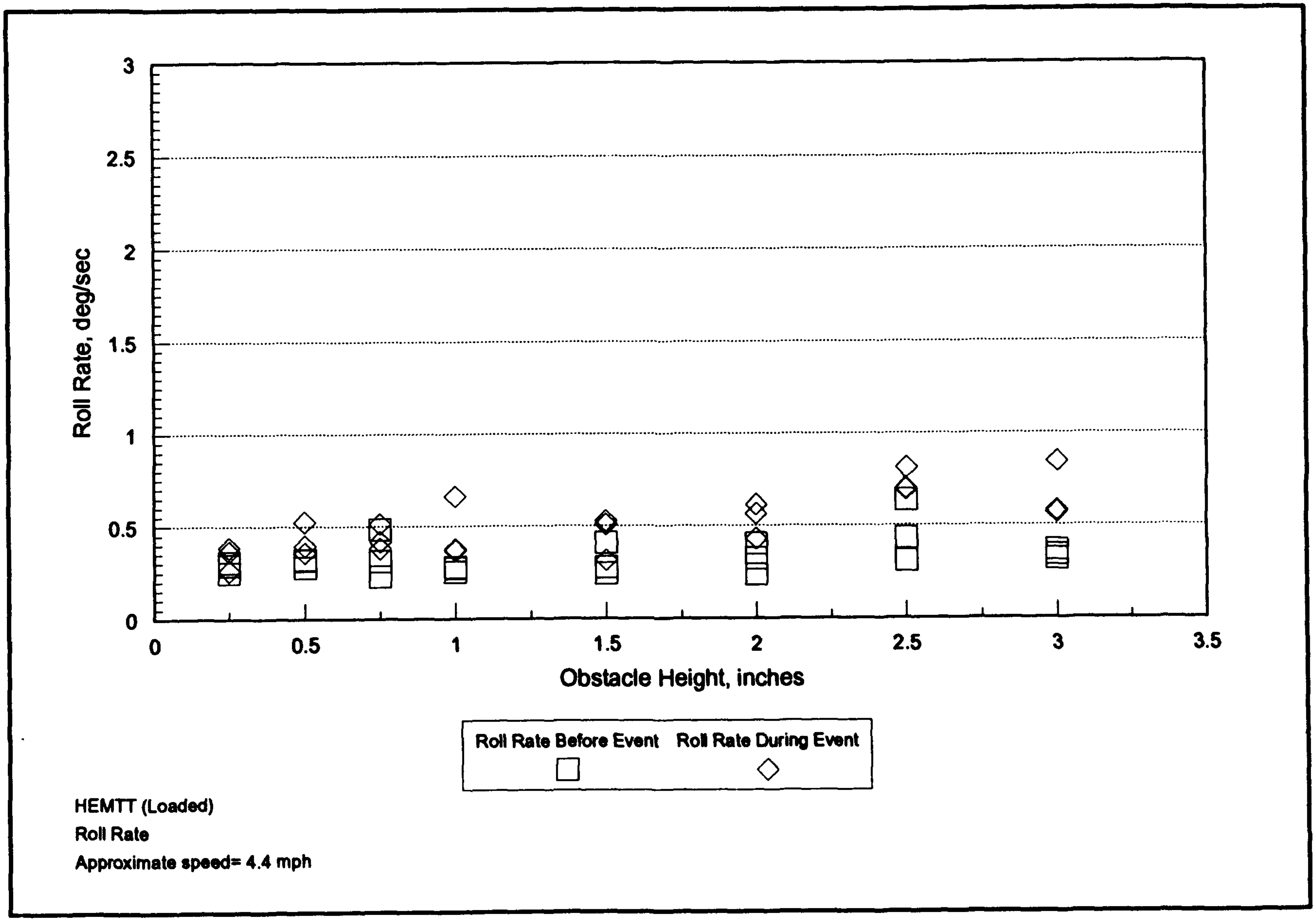

Chart A-10. Peak roll rate versus obstacle height at 4.4 mph (loaded vehicle).

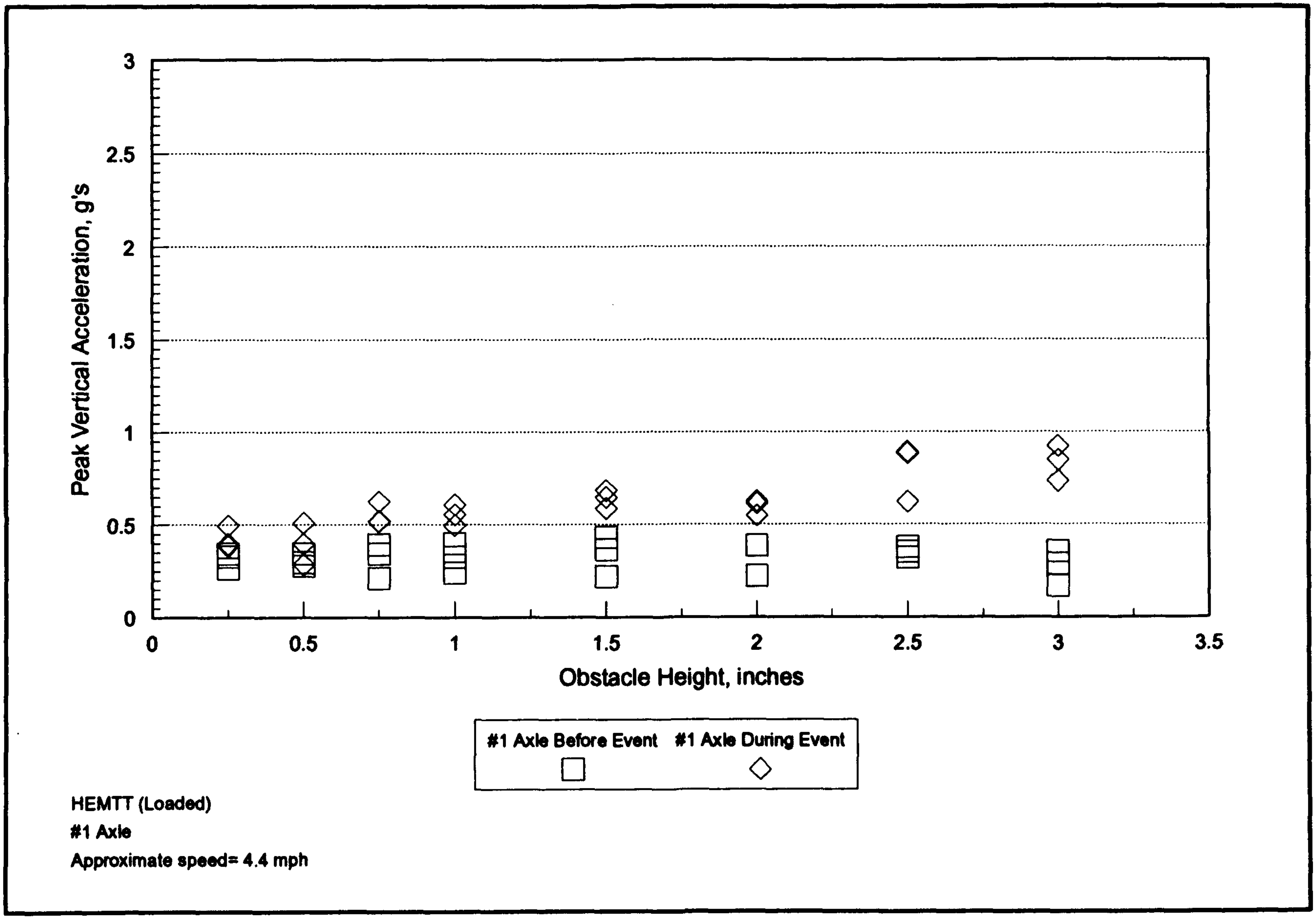

Chart A-11. Peak vertical g's versus obstacle height for axle #1 at 4.4 mph (loaded vehicle).

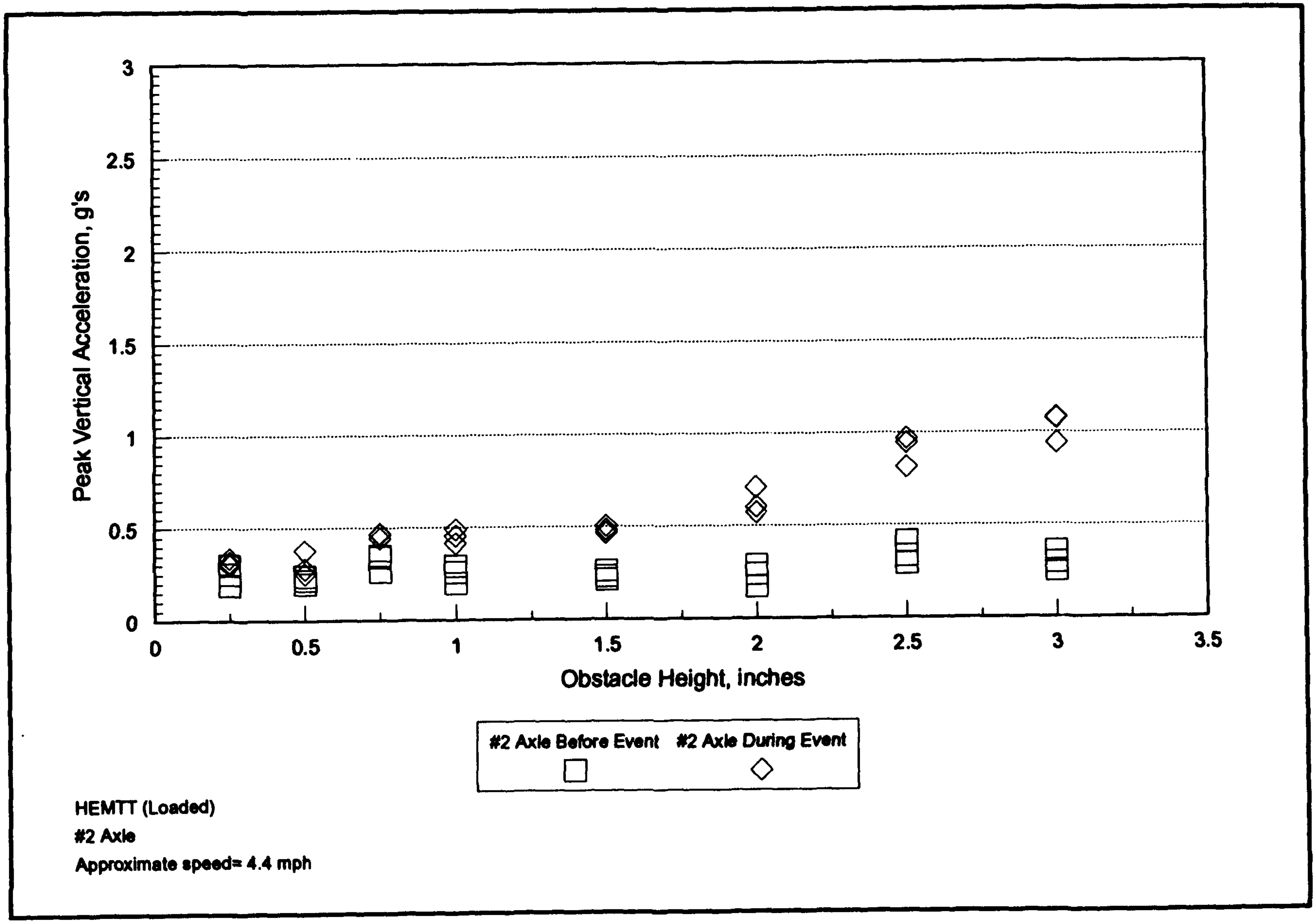

Chart A-12. Peak vertical g's versus obstacle height for axle #2 at 4.4 mph (loaded vehicle).

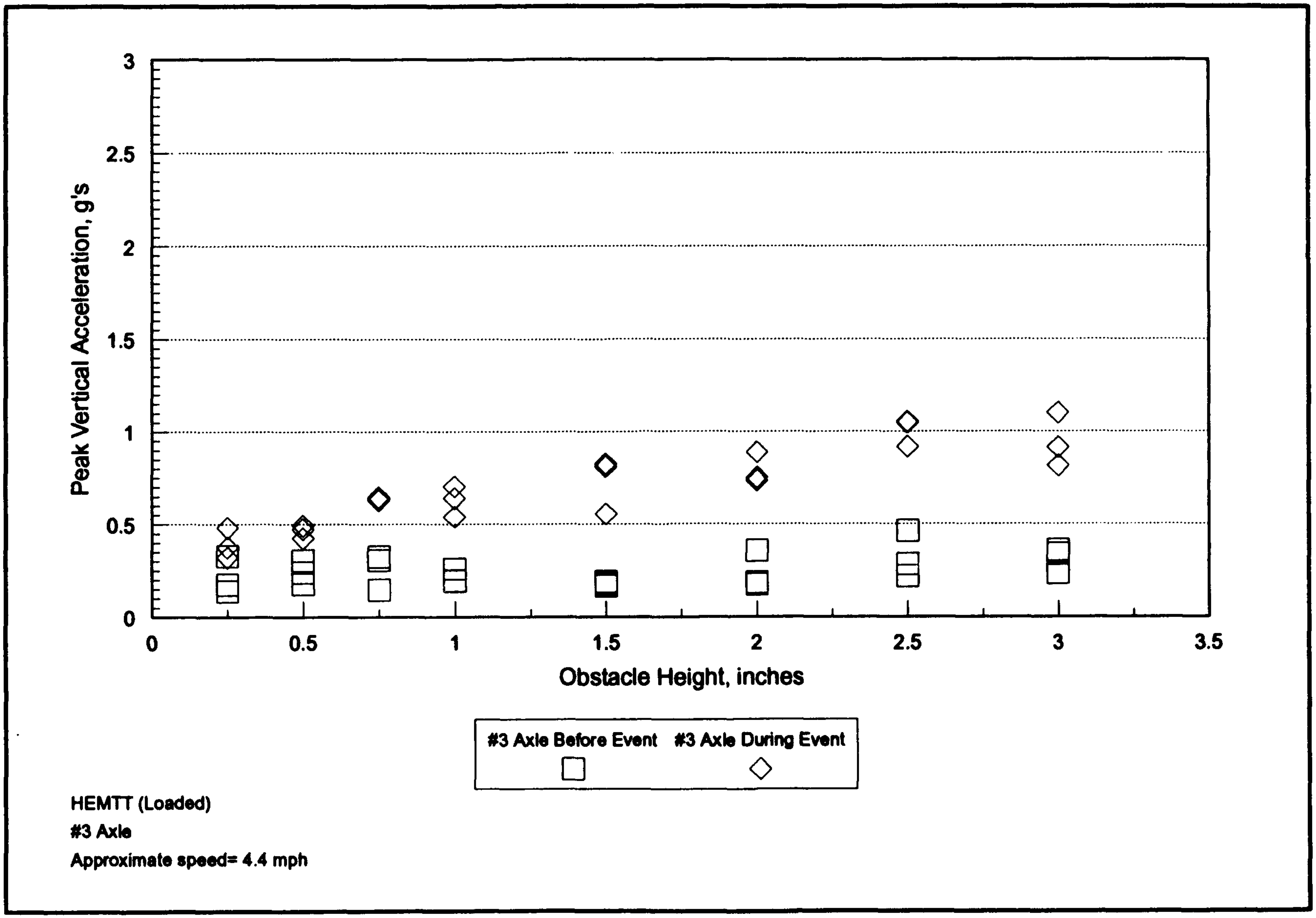

Chart A-13. Peak vertical g's versus obstacle height for axle #3 at 4.4 mph (loaded vehicle).

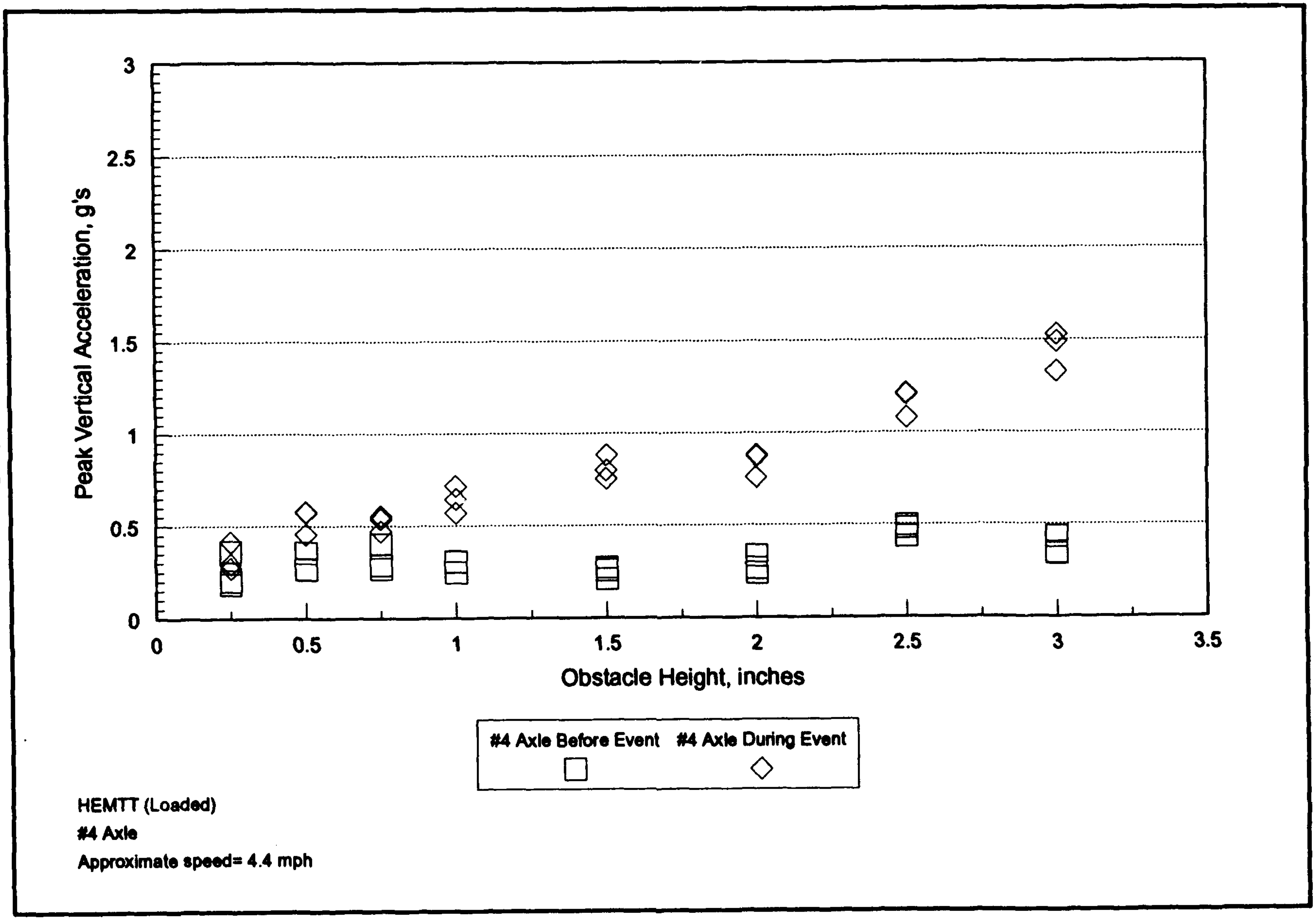

Chart A-14. Peak vertical g's versus obstacle height for axle #4 at 4.4 mph (loaded vehicle).

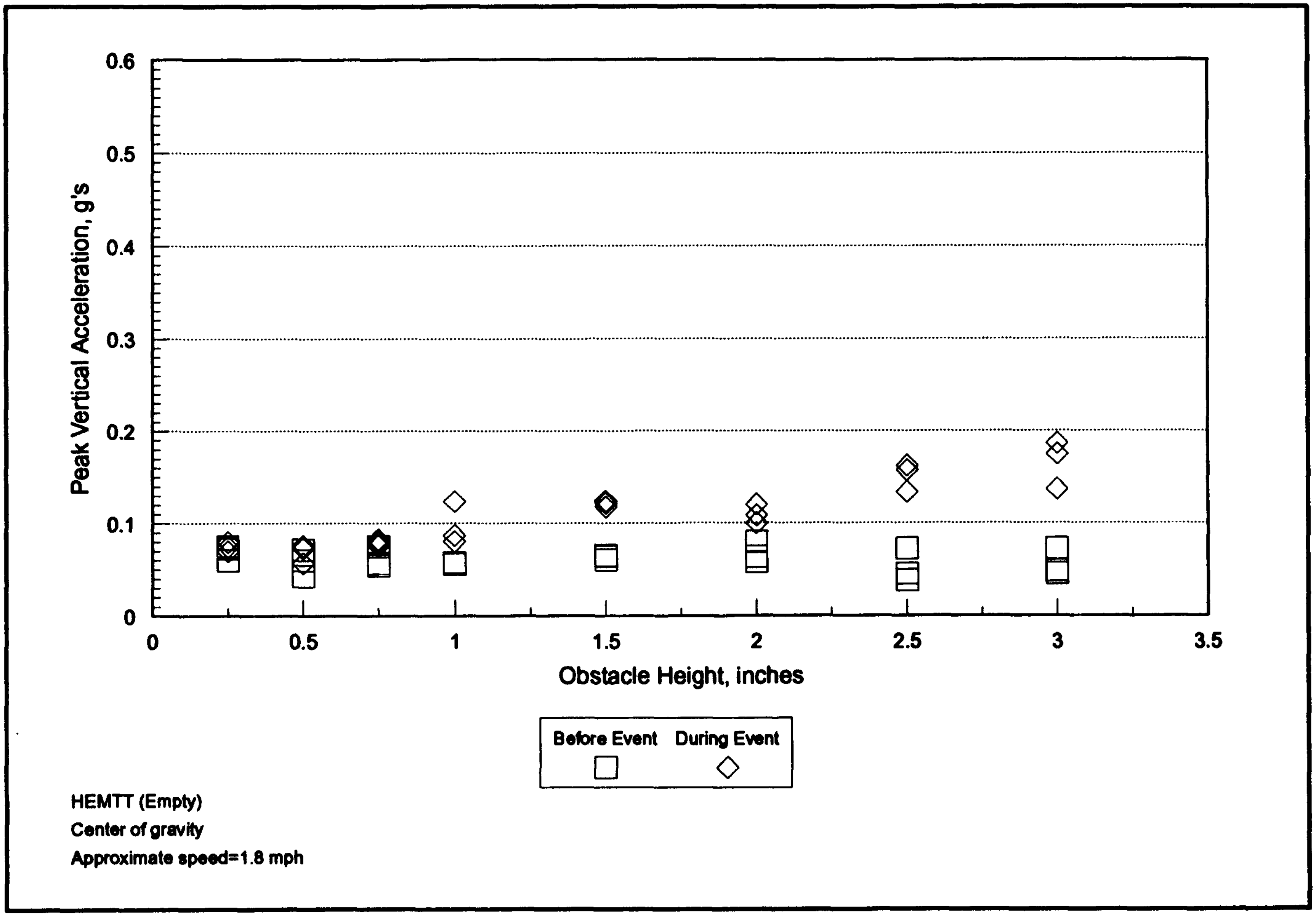

Chart A-15. Peak vertical g's versus obstacle height for c.g. at 1.8 mph (empty vehicle).

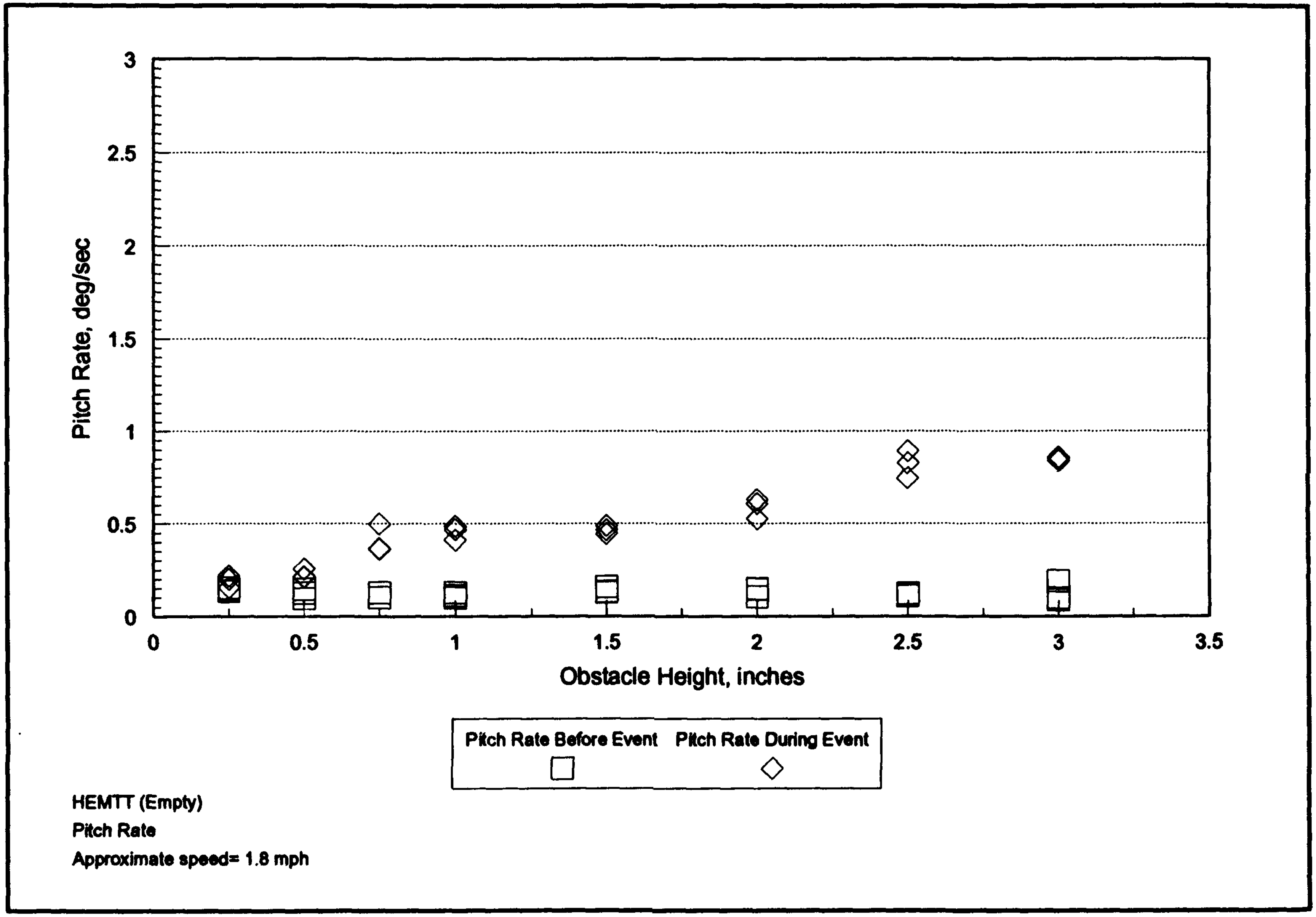

Chart A-16. Peak pitch rate versus obstacle height at 1.8 mph (empty vehicle).

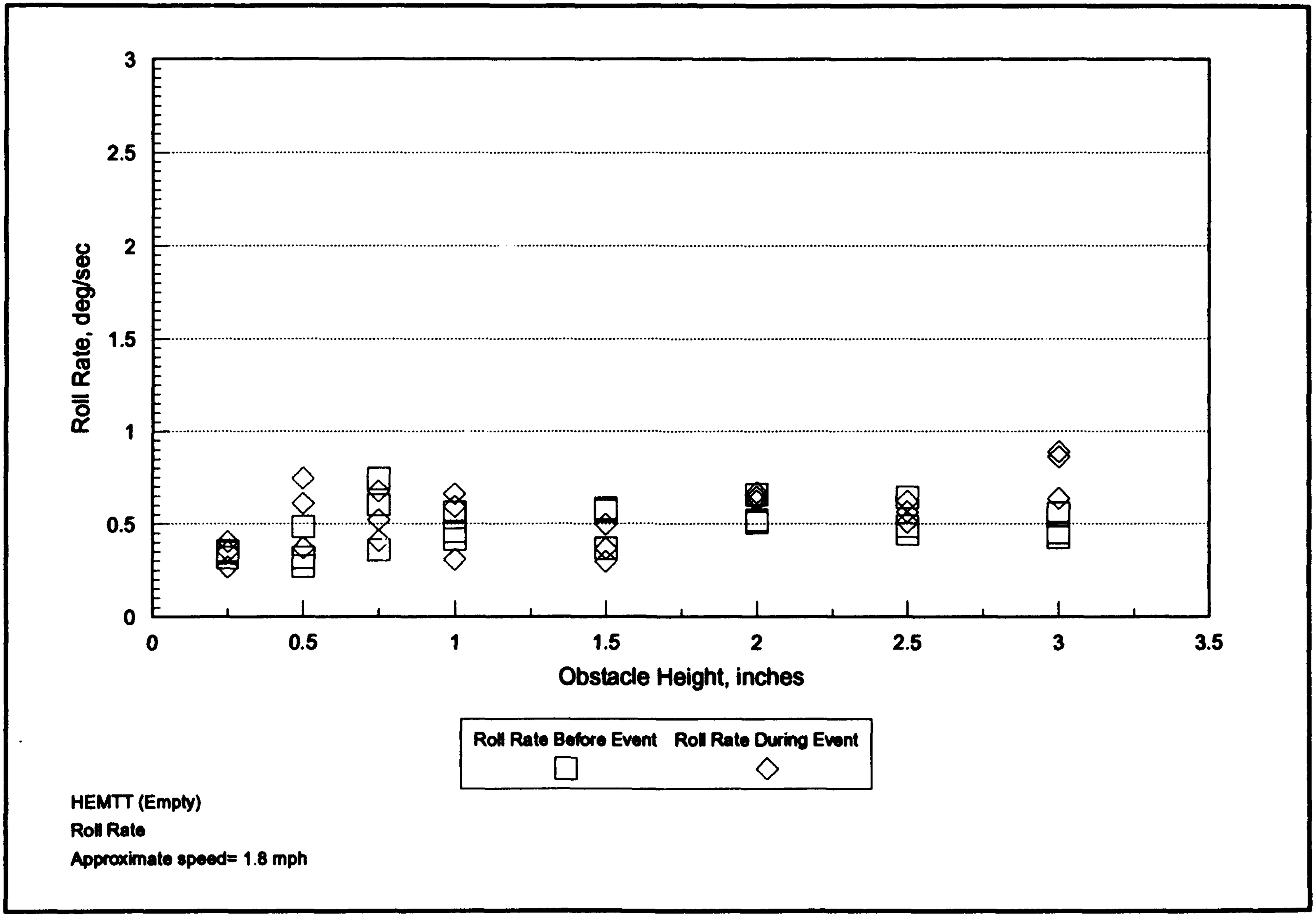

Chart A-17. Peak roll rate versus obstacle height at 1.8 mph (empty vehicle).

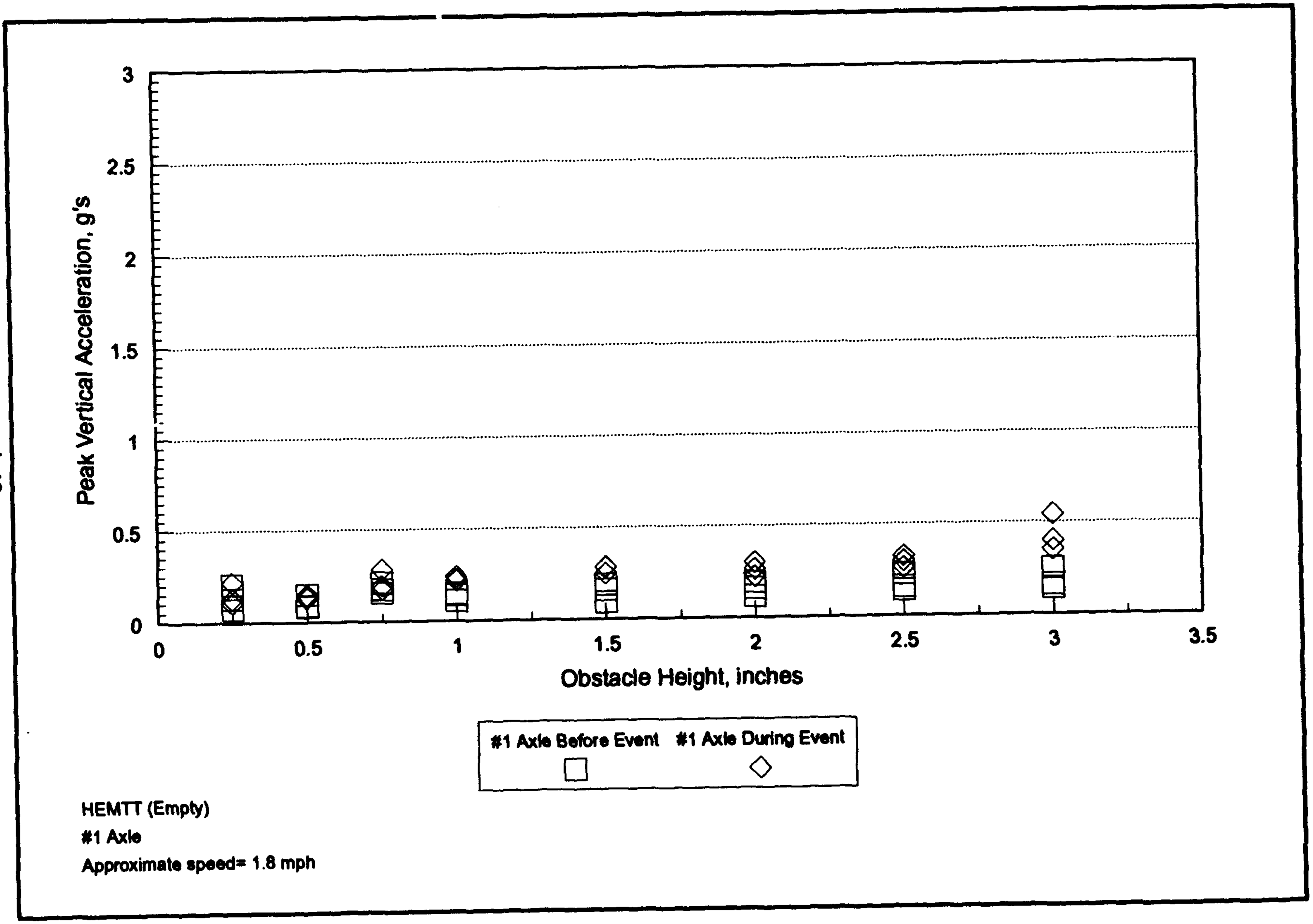

Chart A-18. Peak vertical g's versus obstacle height for axle #1 at 1.8 mph (empty vehicle).

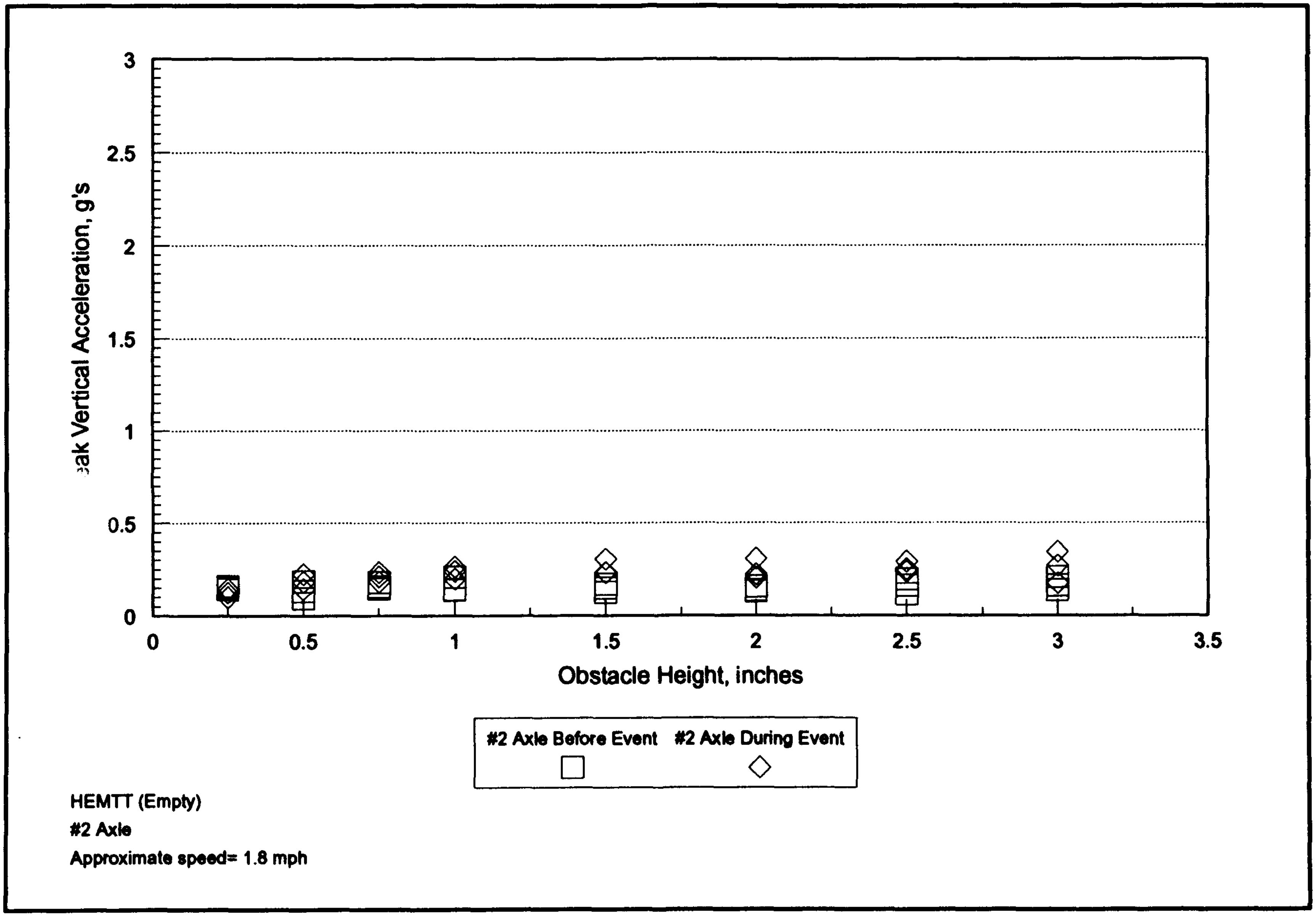

Chart A-19. Peak vertical g's versus obstacle height for axle #2 at 1.8 mph (empty vehicle).

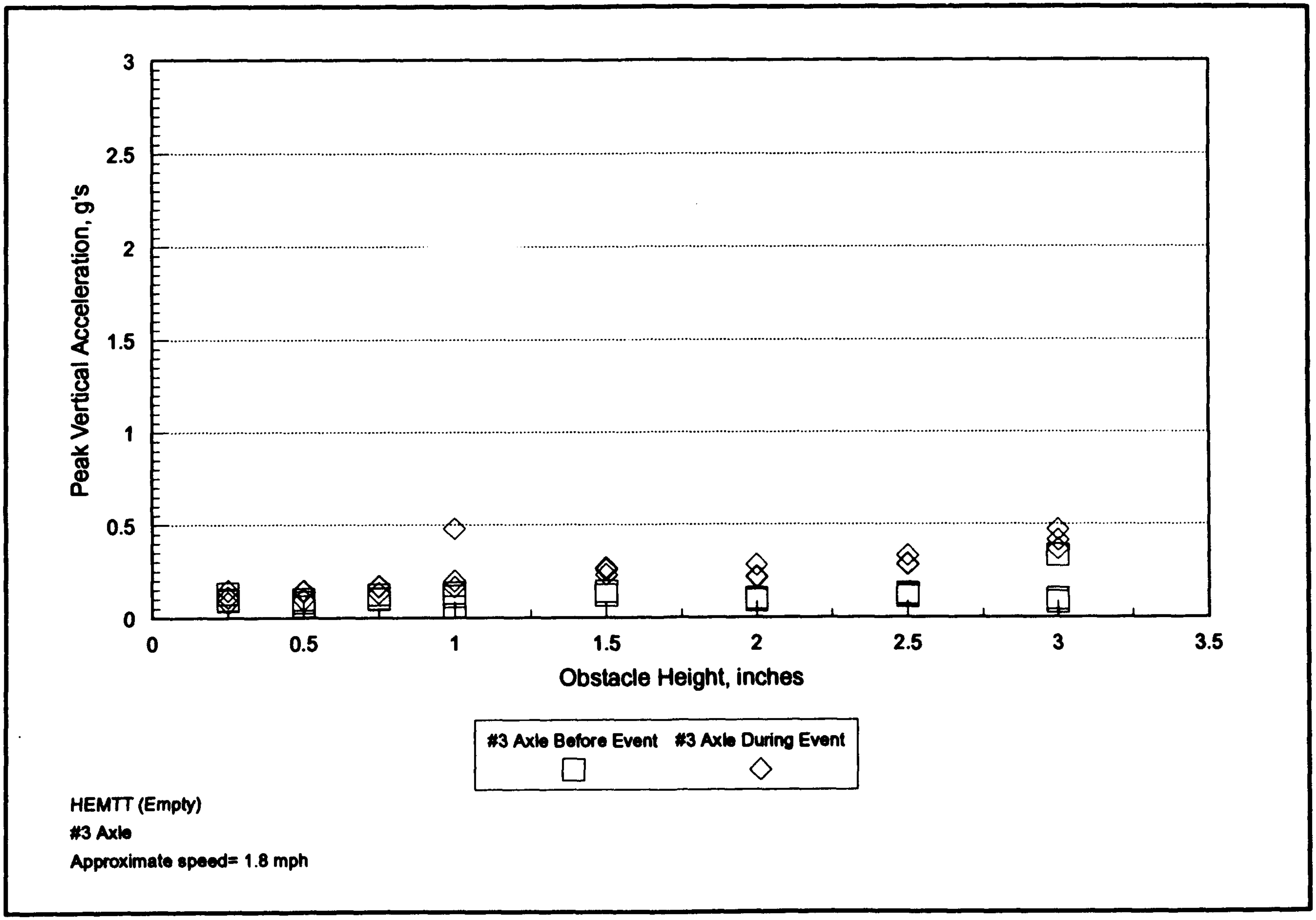

Chart A-20. Peak vertical g's versus obstacle height for axle #3 at 1.8 mph (empty vehicle).

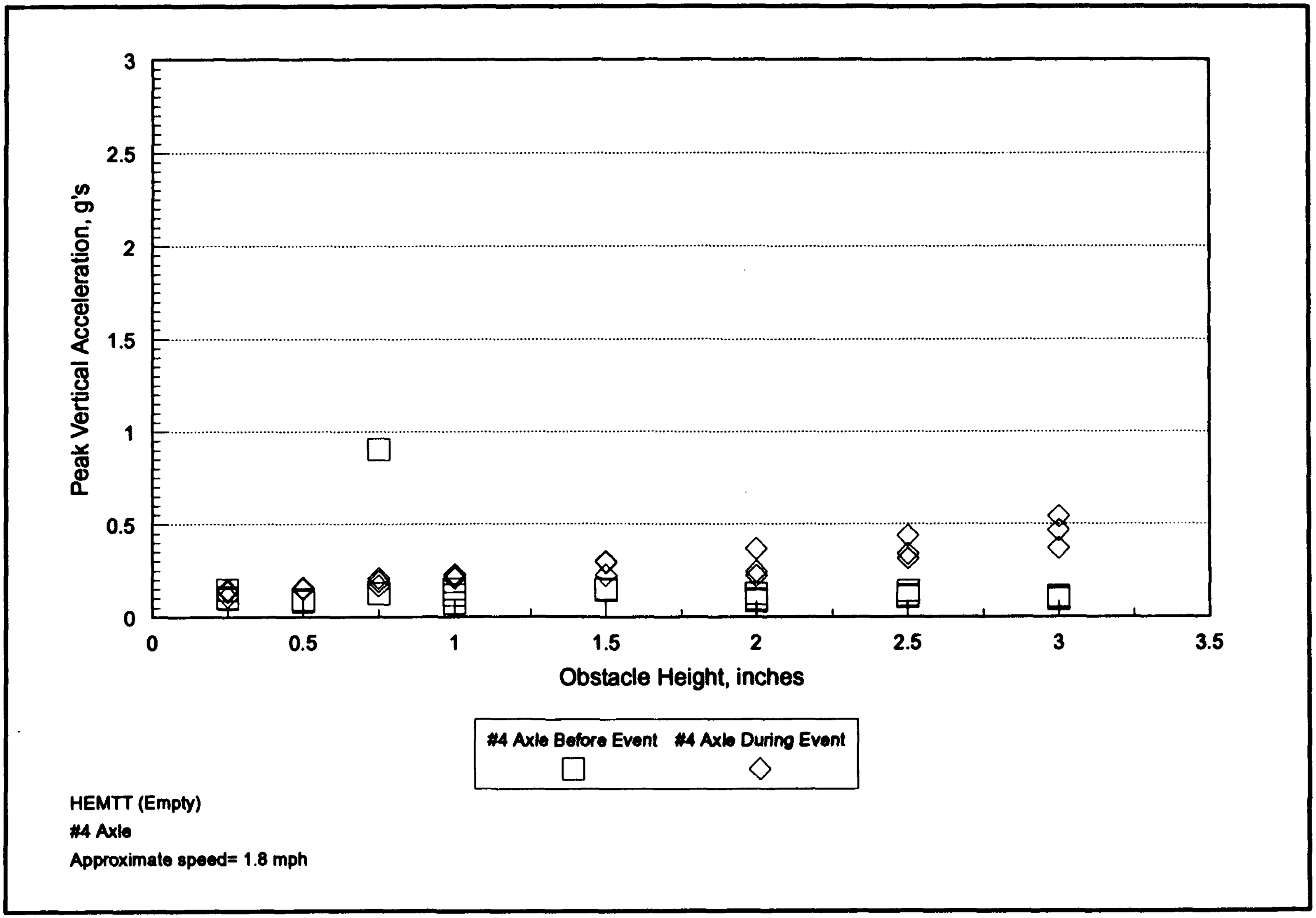

Chart A-21. Peak vertical g's versus obstacle height for axle #4 at 1.8 mph (empty vehicle).

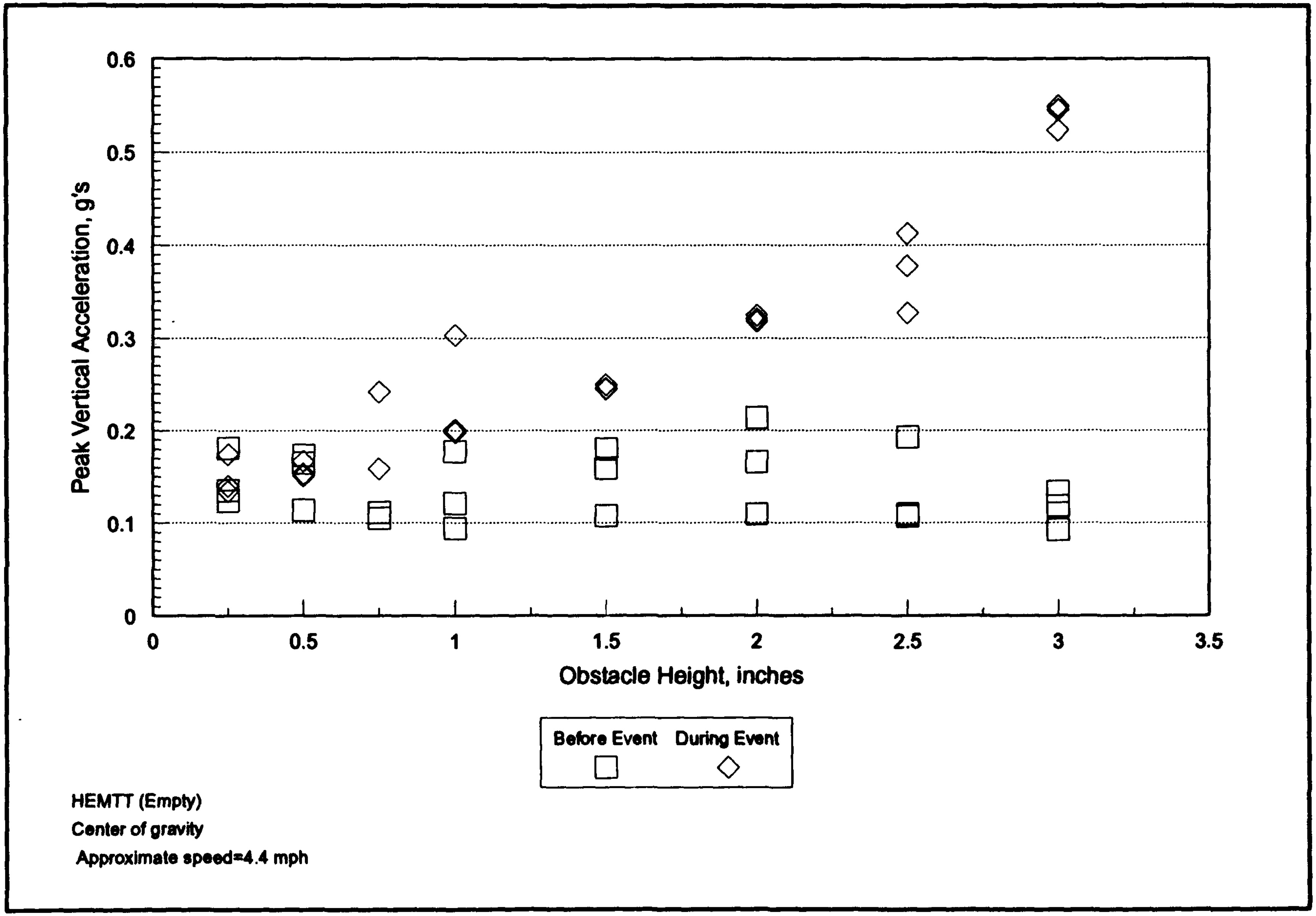

Chart A-22. Peak vertical g's versus obstacle height for c.g. at 4.4 mph (empty vehicle).

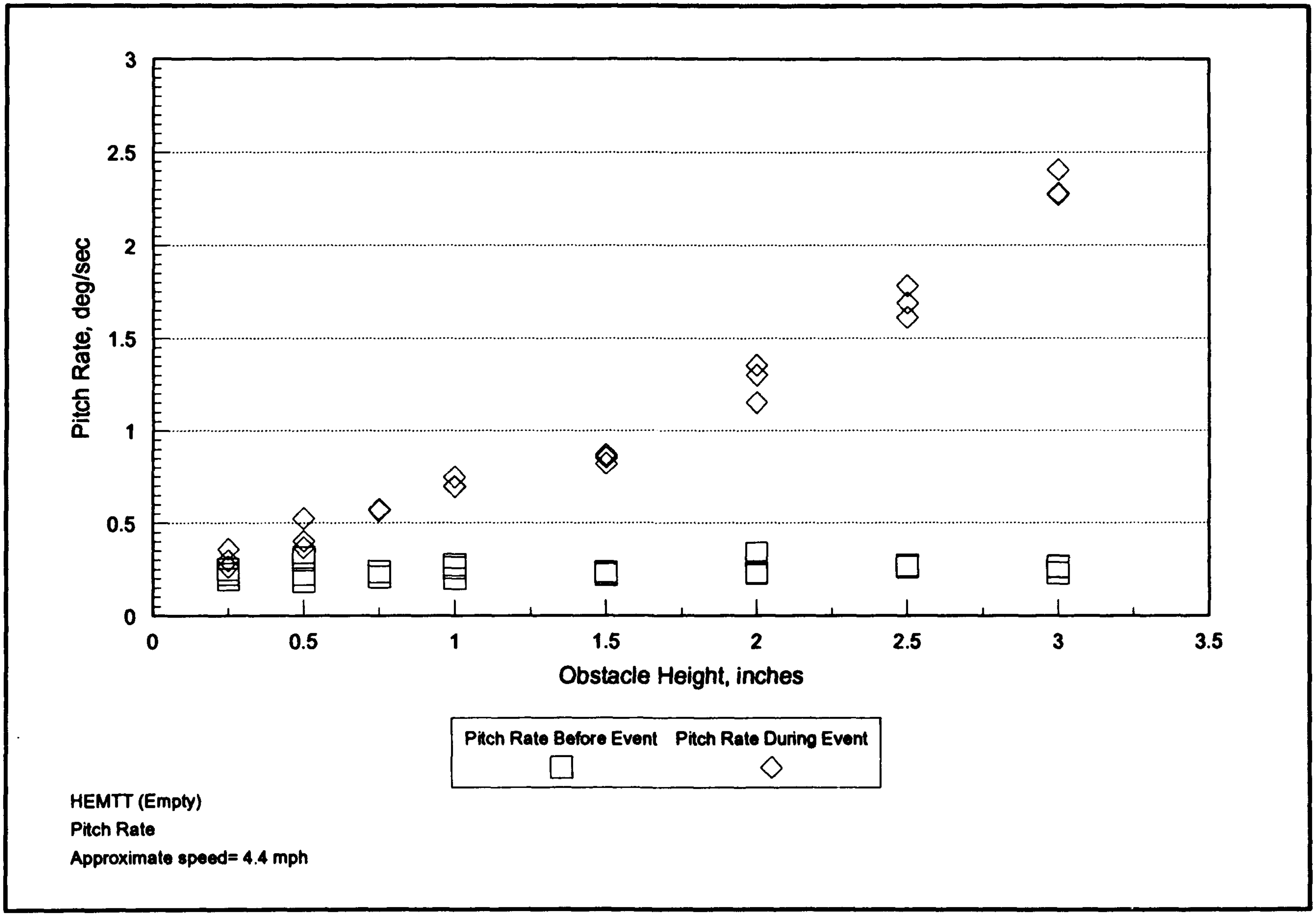

Chart A-23. Peak pitch rate versus obstacle height at 4.4 mph (empty vehicle).

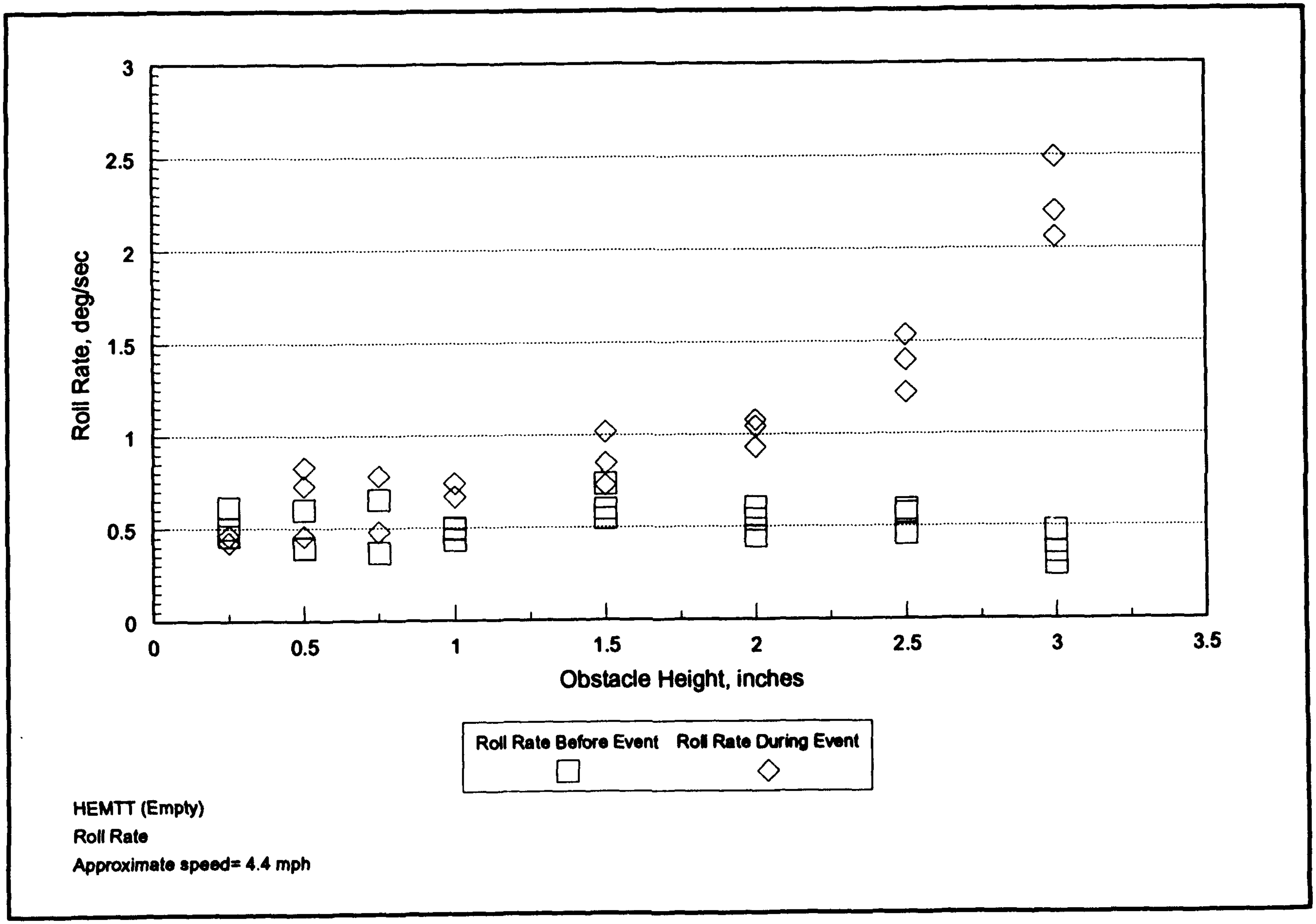

Chart A-24. Peak roll rate versus obstacle height at 4.4 mph (empty vehicle).

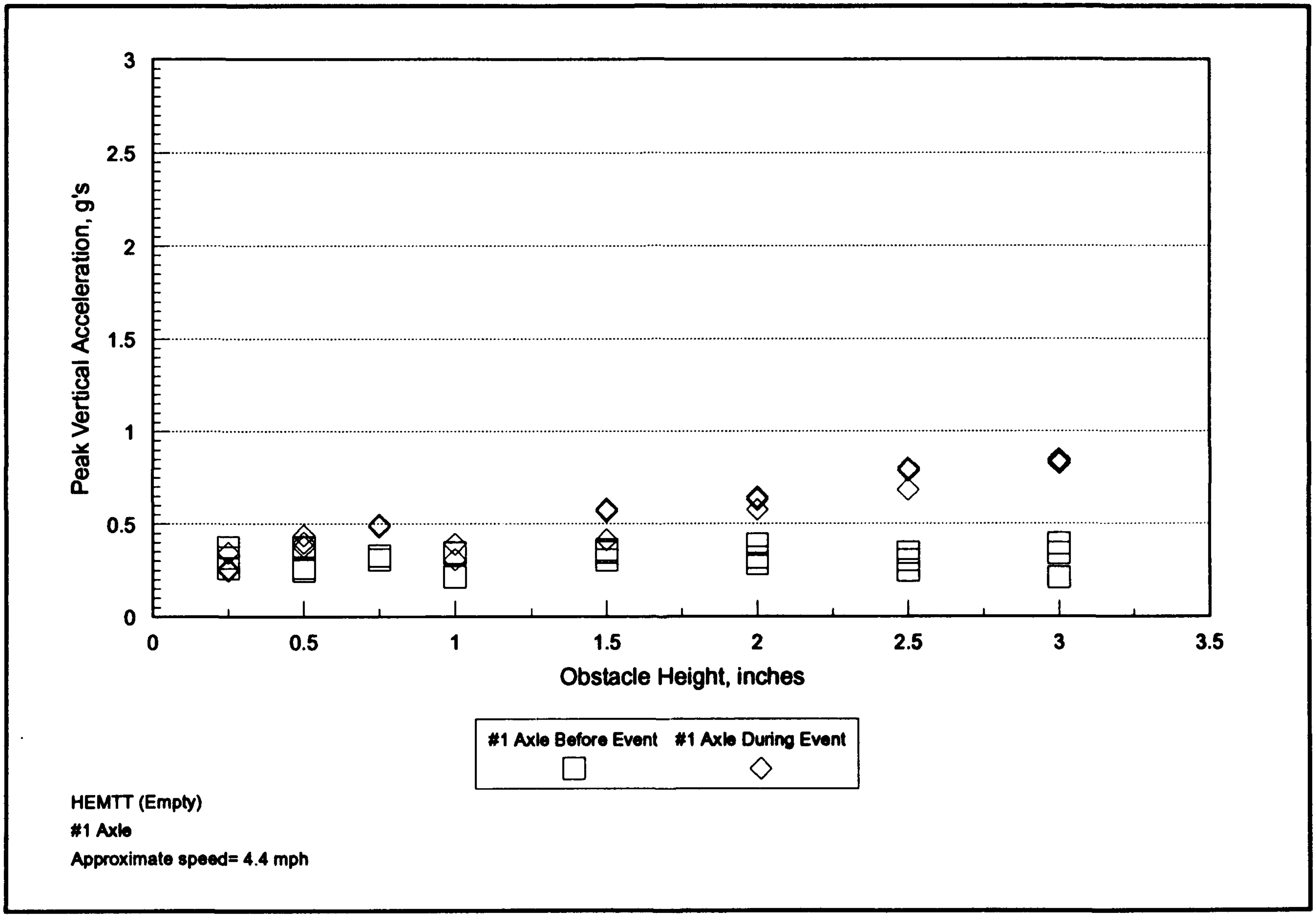

Chart A-25. Peak vertical g's versus obstacle height for axle #1 at 4.4 mph (empty vehicle).

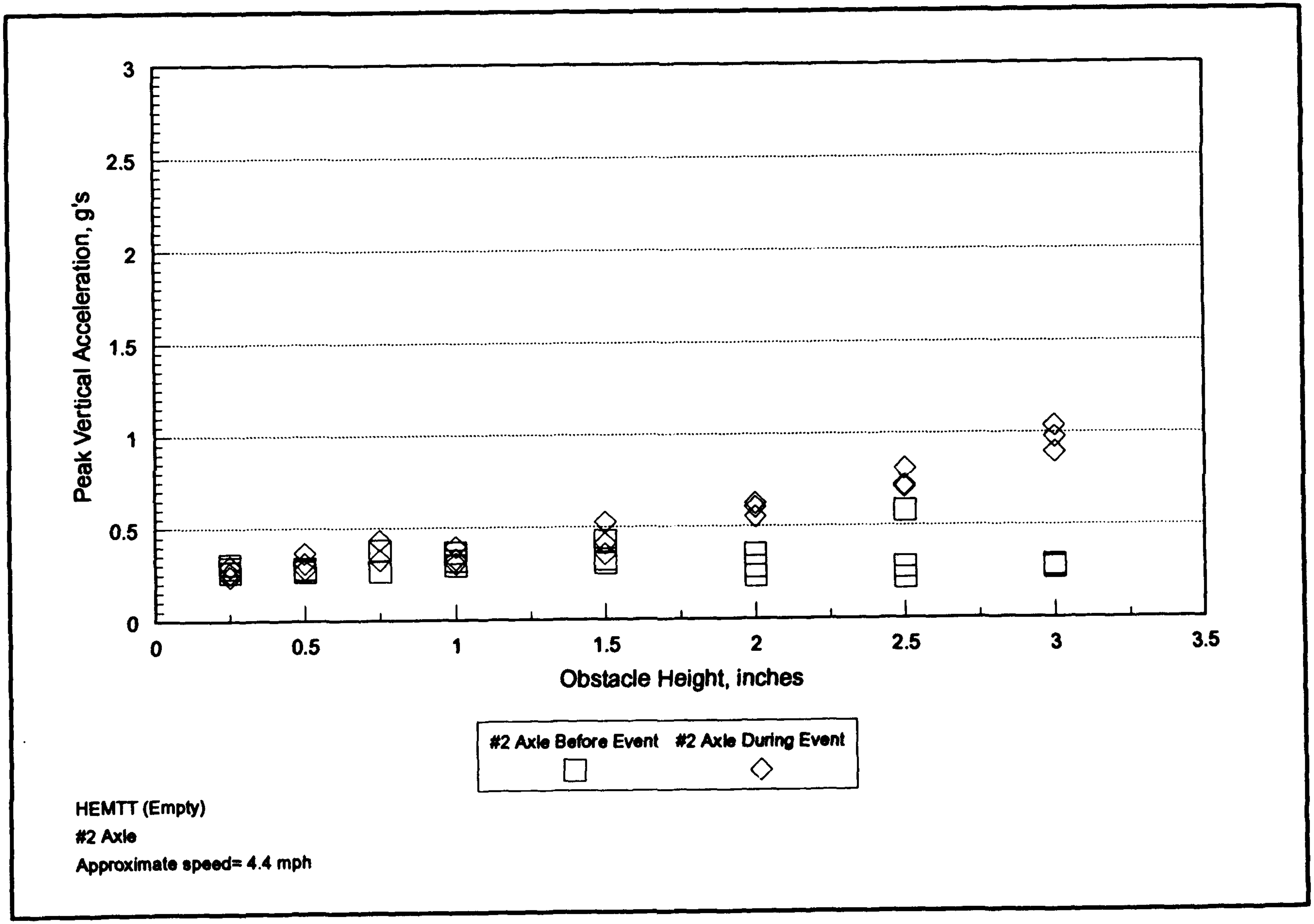

Chart A-26. Peak vertical g's versus obstacle height for axle #2 at 4.4 mph (empty vehicle).

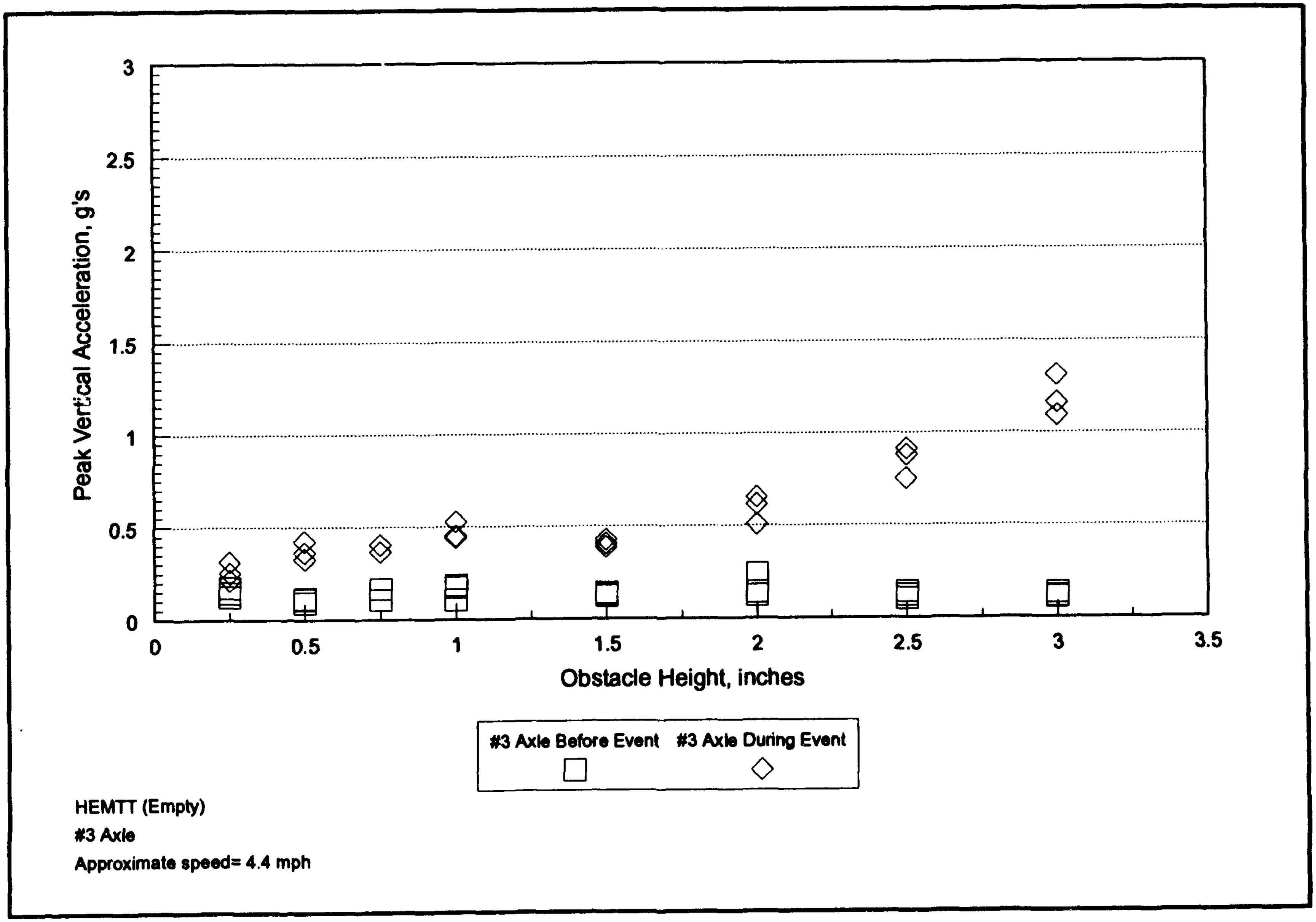

Chart A-27. Peak vertical g's versus obstacle height for axle #3 at 4.4 mph (empty vehicle).

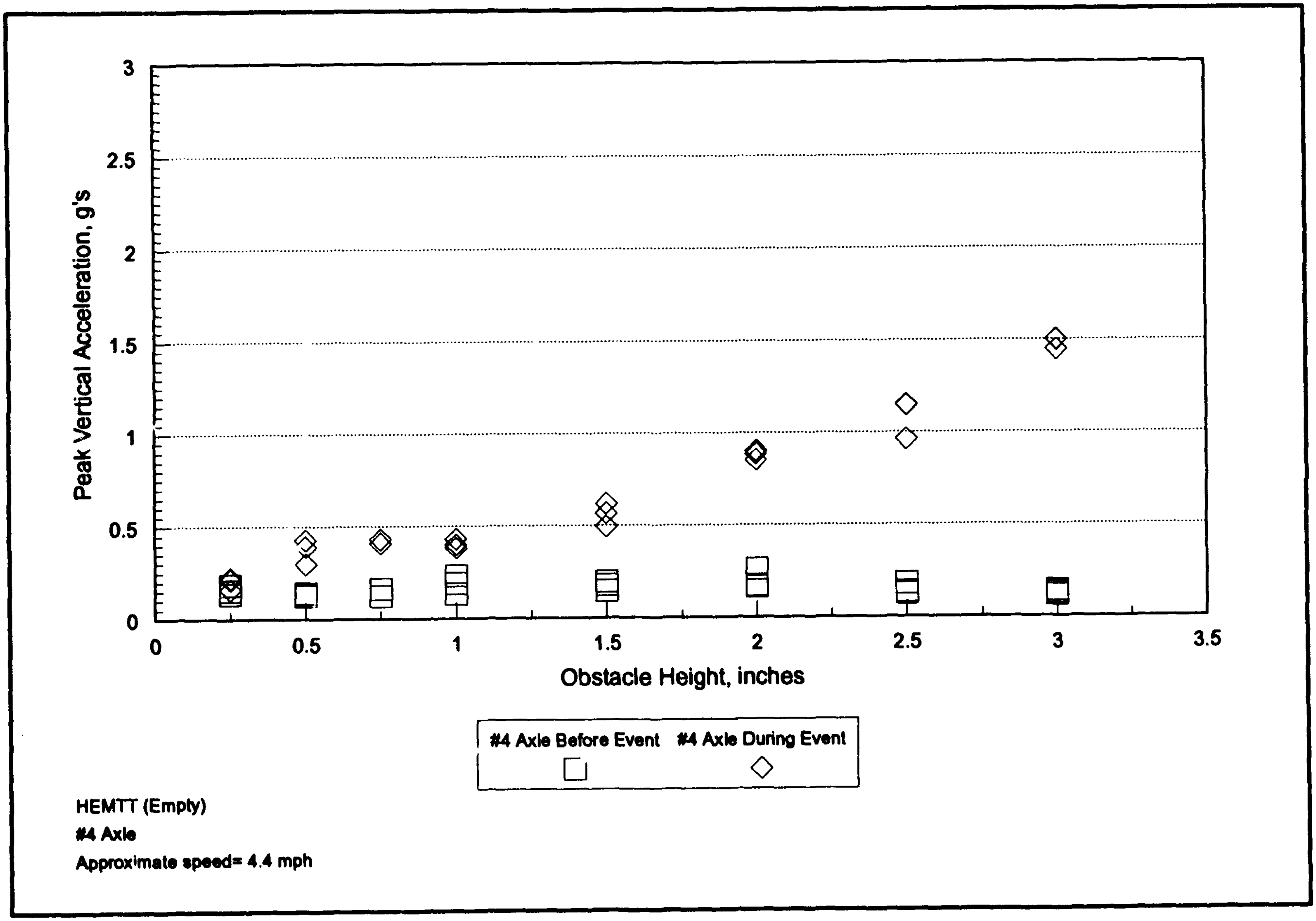

Chart A-28. Peak vertical g's versus obstacle height for axle #4 at 4.4 mph (empty vehicle).

APPENDIX B

DOMINANT FREQUENCY PLOTS VERSUS OBSTACLE HEIGHT

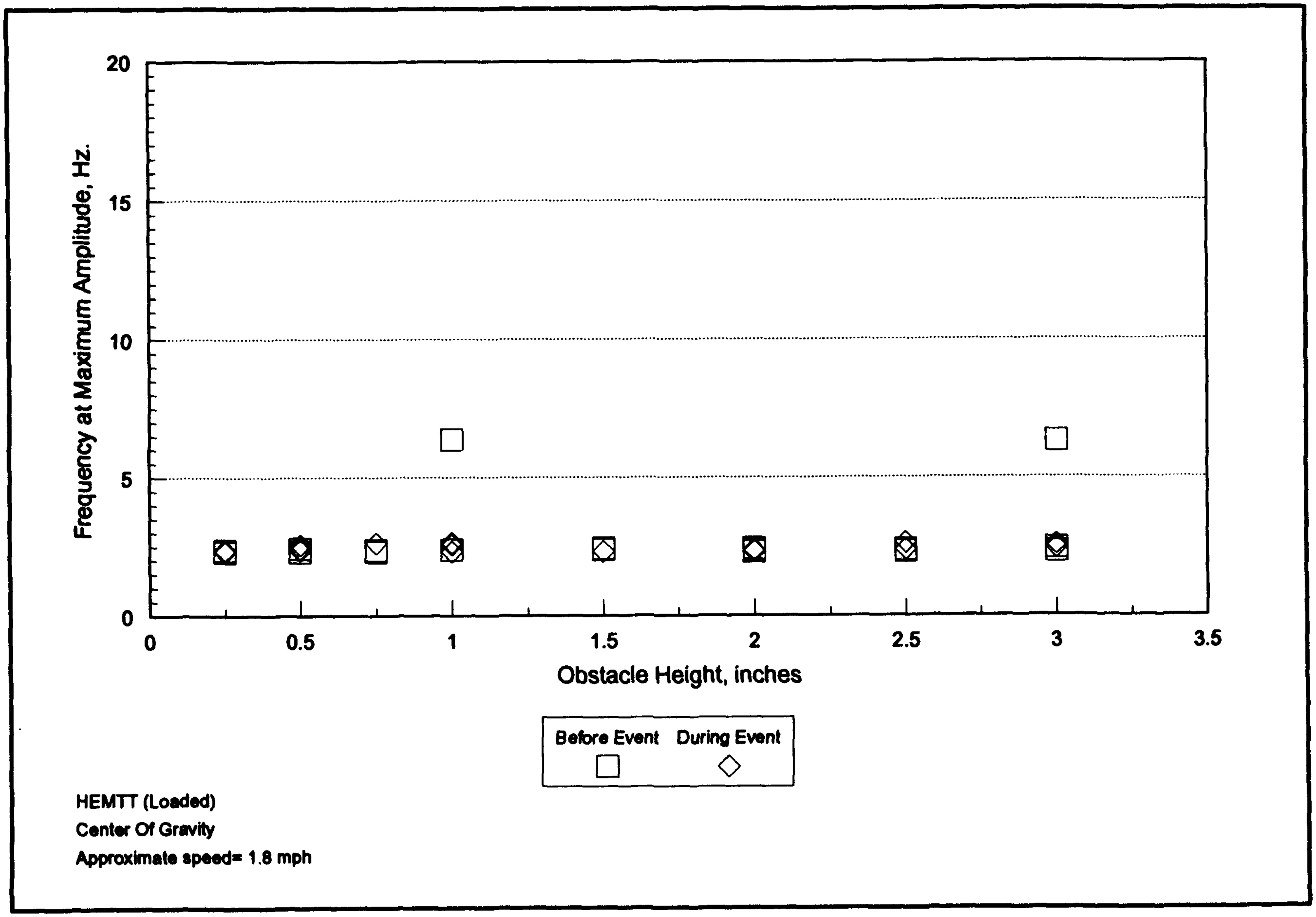

Chart B-1. Frequency at maximum amplitude versus obstacle height for c.g. at 1.8 mph (loaded vehicle).

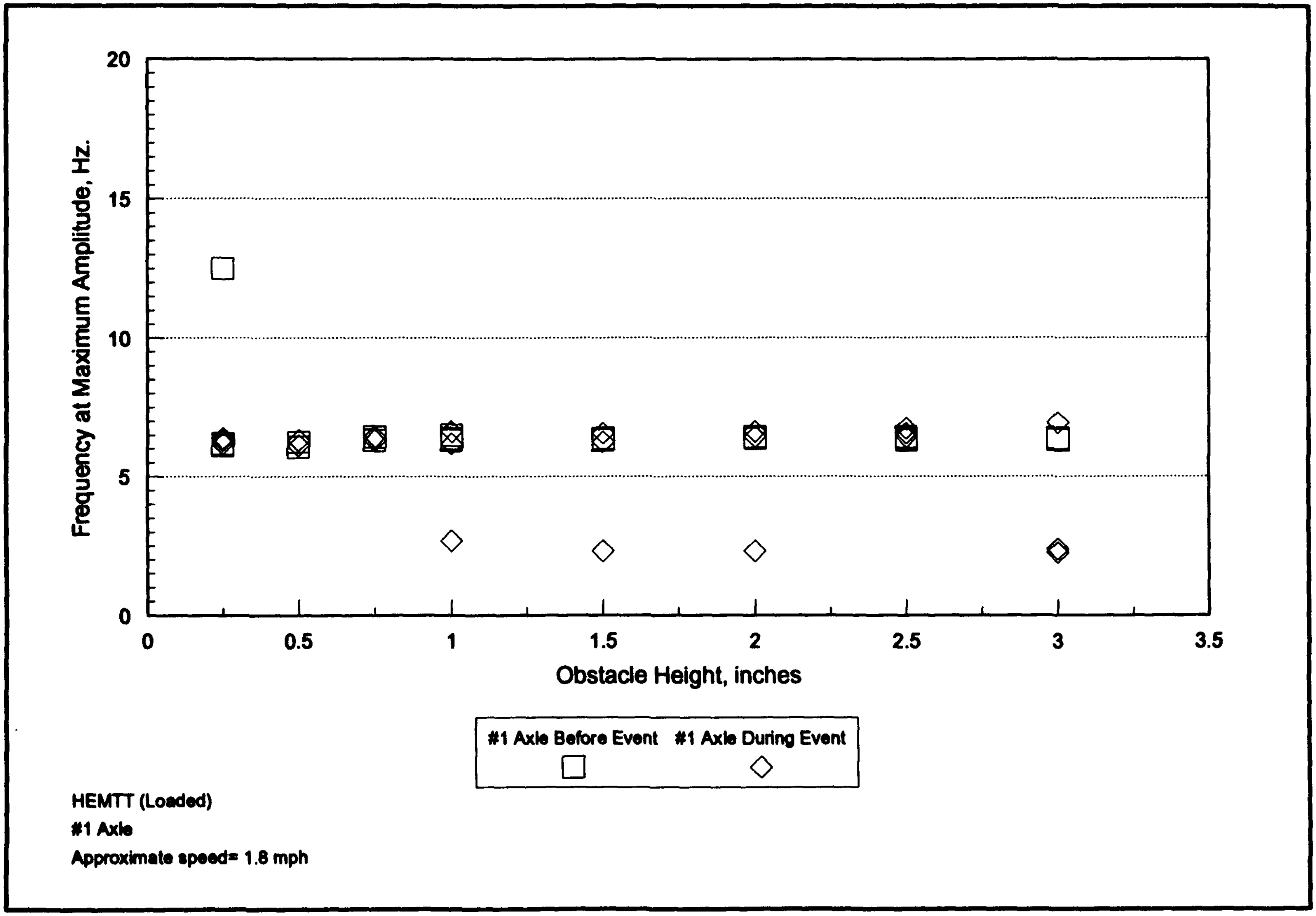

Chart B-2. Frequency at maximum amplitude versus obstacle height for axle #1 at 1.8 mph (loaded vehicle).

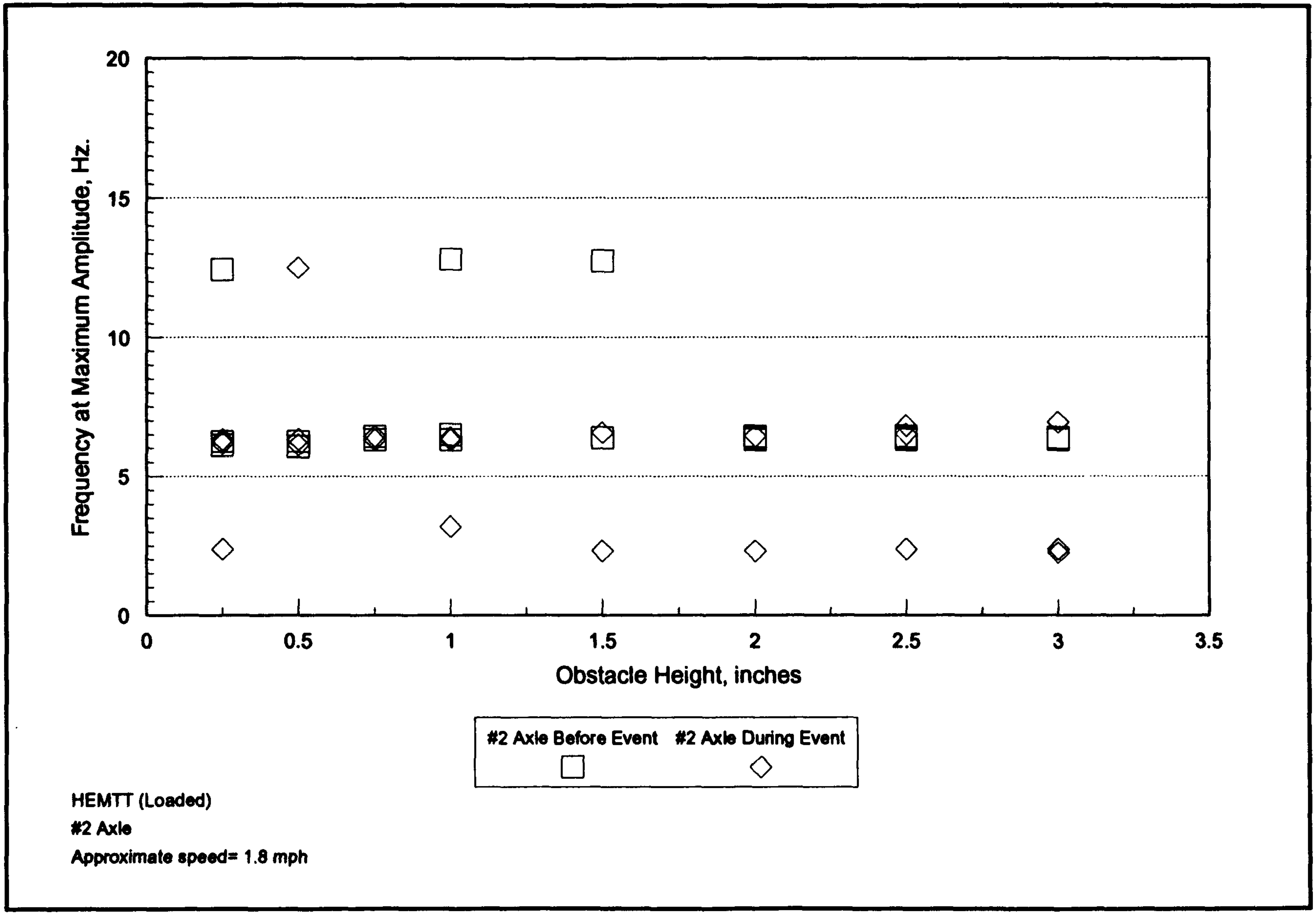

Chart B-3. Frequency at maximum amplitude versus obstacle height for axle #2 at 1.8 mph (loaded vehicle).

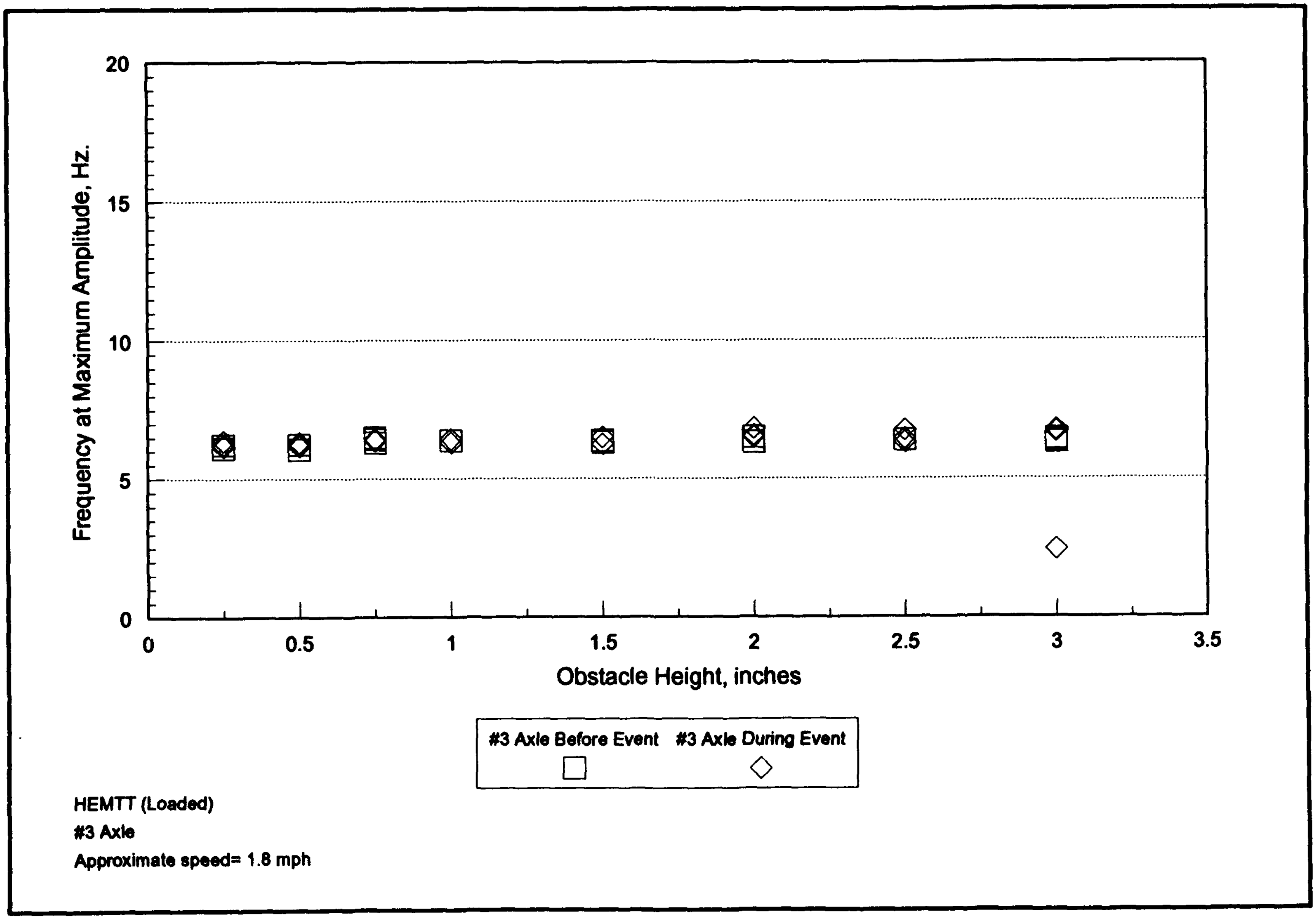

Chart B-4. Frequency at maximum amplitude versus obstacle height for axle #3 at 1.8 mph (loaded vehicle).

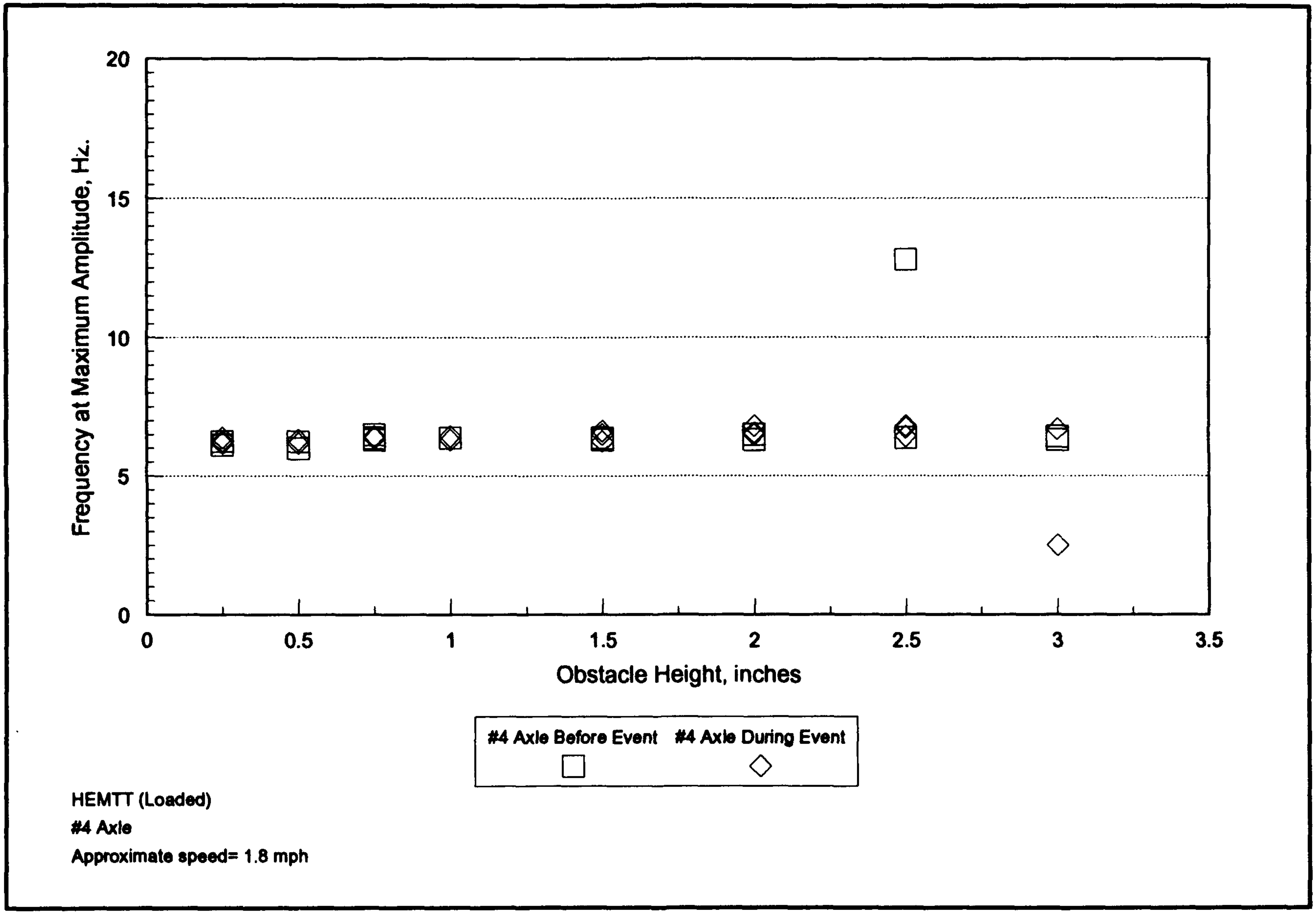

Chart B-5. Frequency at maximum amplitude versus obstacle height for axle #4 at 1.8 mph (loaded vehicle).

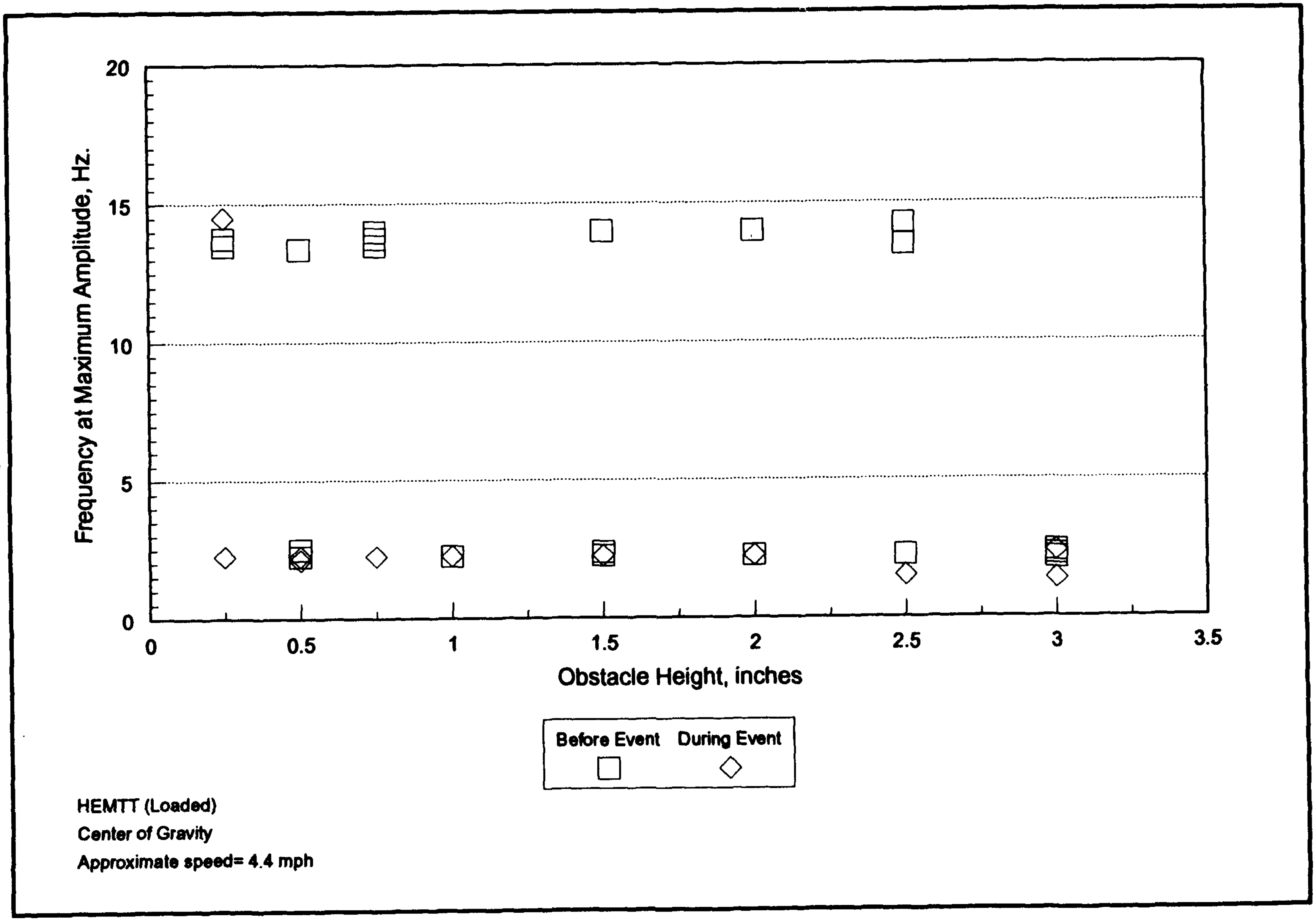

Chart B-6. Frequency at maximum amplitude versus obstacle height for c.g. at 4.4 mph (loaded vehicle).

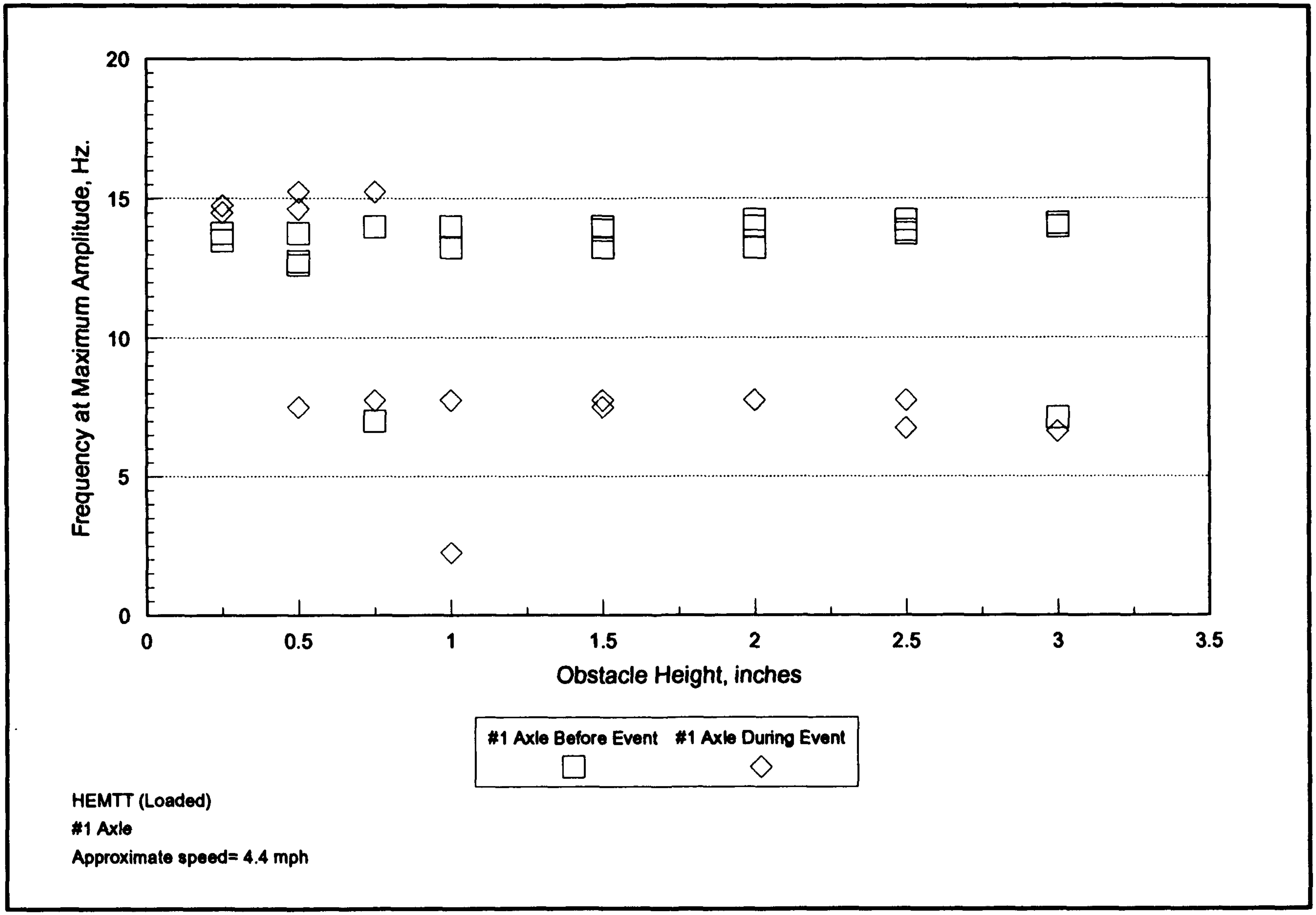

Chart B-7. Frequency at maximum amplitude versus obstacle height for axle #1 at 4.4 mph (loaded vehicle).

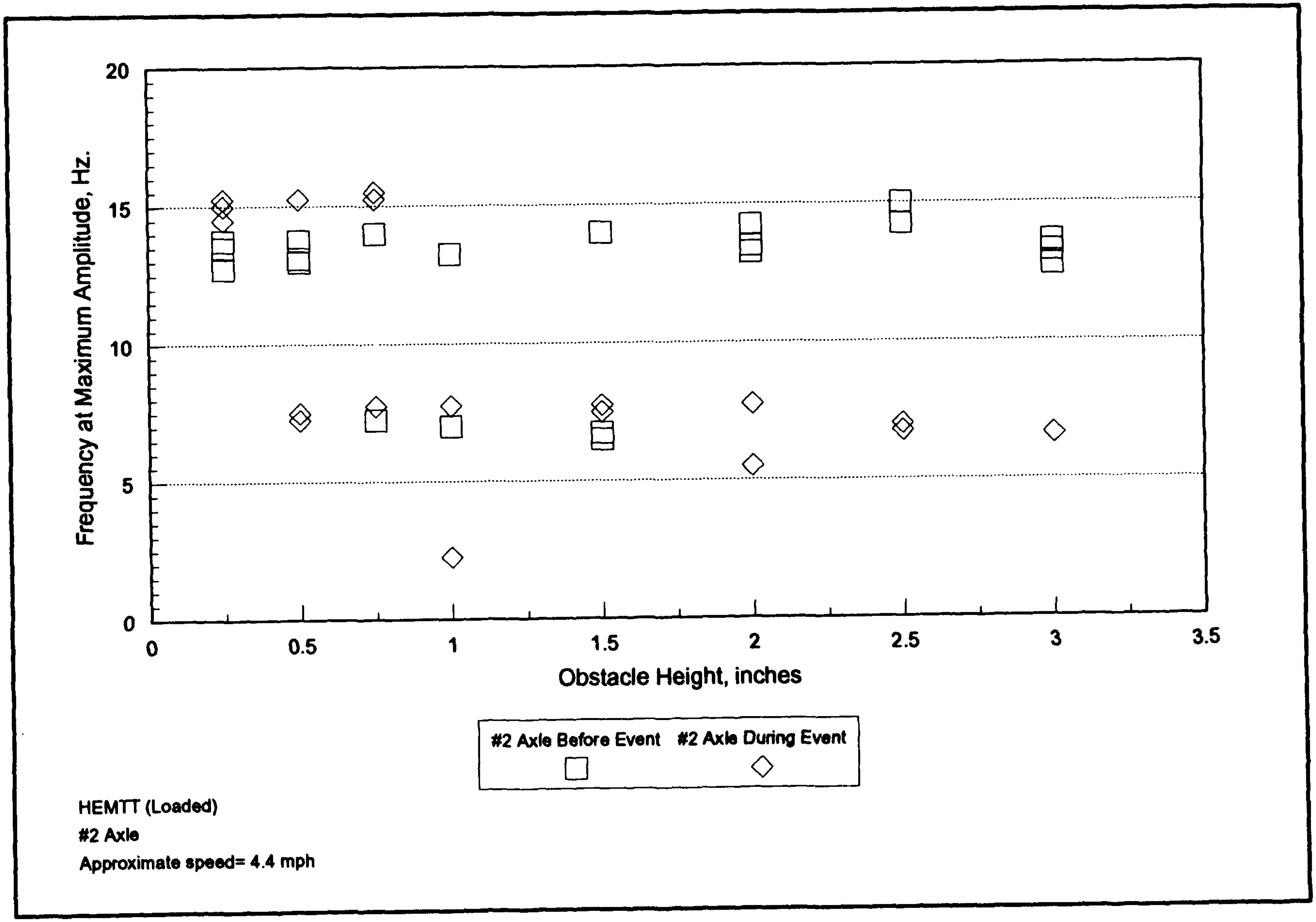

Chart B-8. Frequency at maximum amplitude versus obstacle height for axle #2 at 4.4 mph (loaded vehicle).

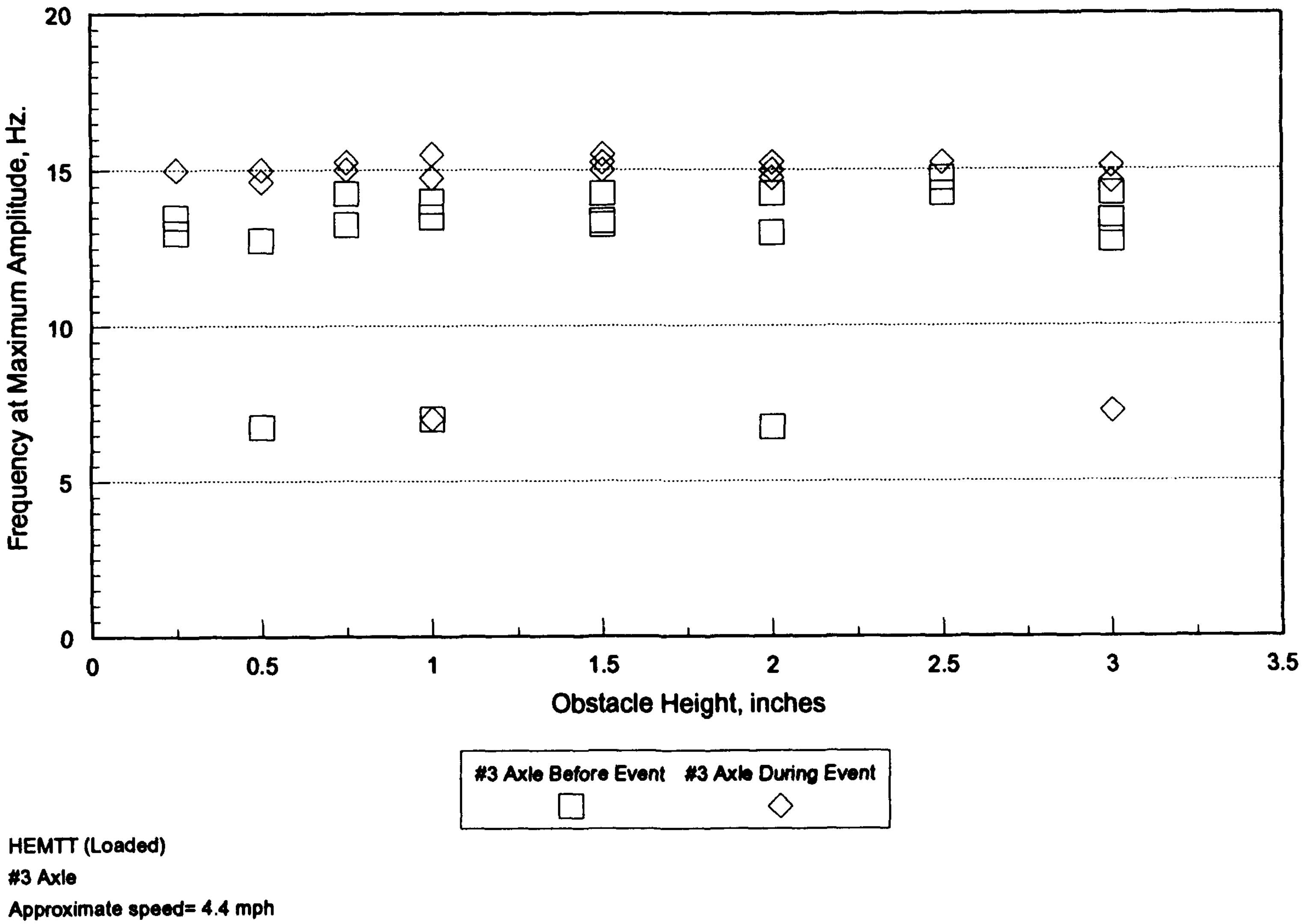

Chart B-9. Frequency at maximum amplitude versus obstacle height for axle #3 at 4.4 mph (loaded vehicle).

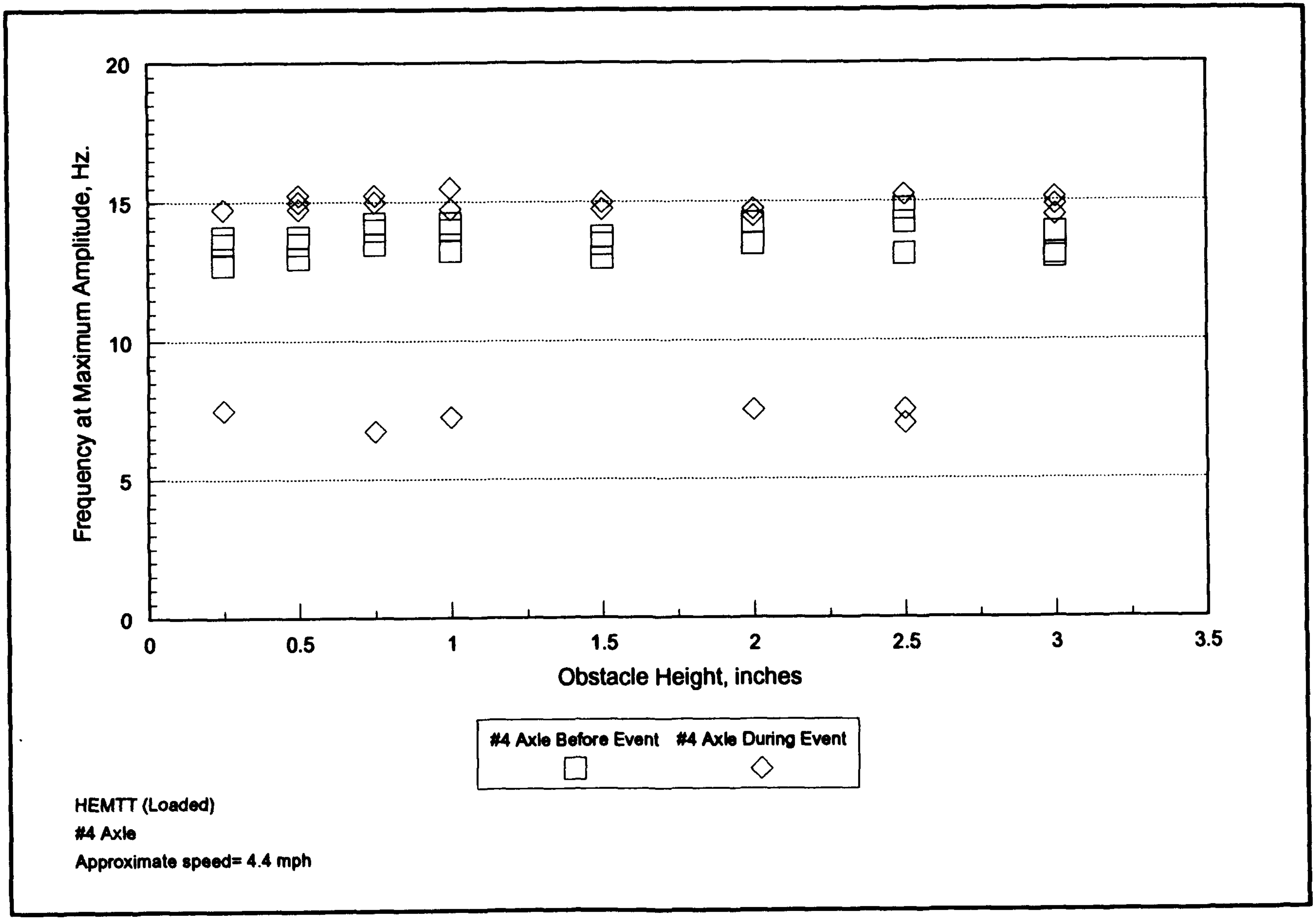

Chart B-10. Frequency at maximum amplitude versus obstacle height for axle #4 at 4.4 mph (loaded vehicle).

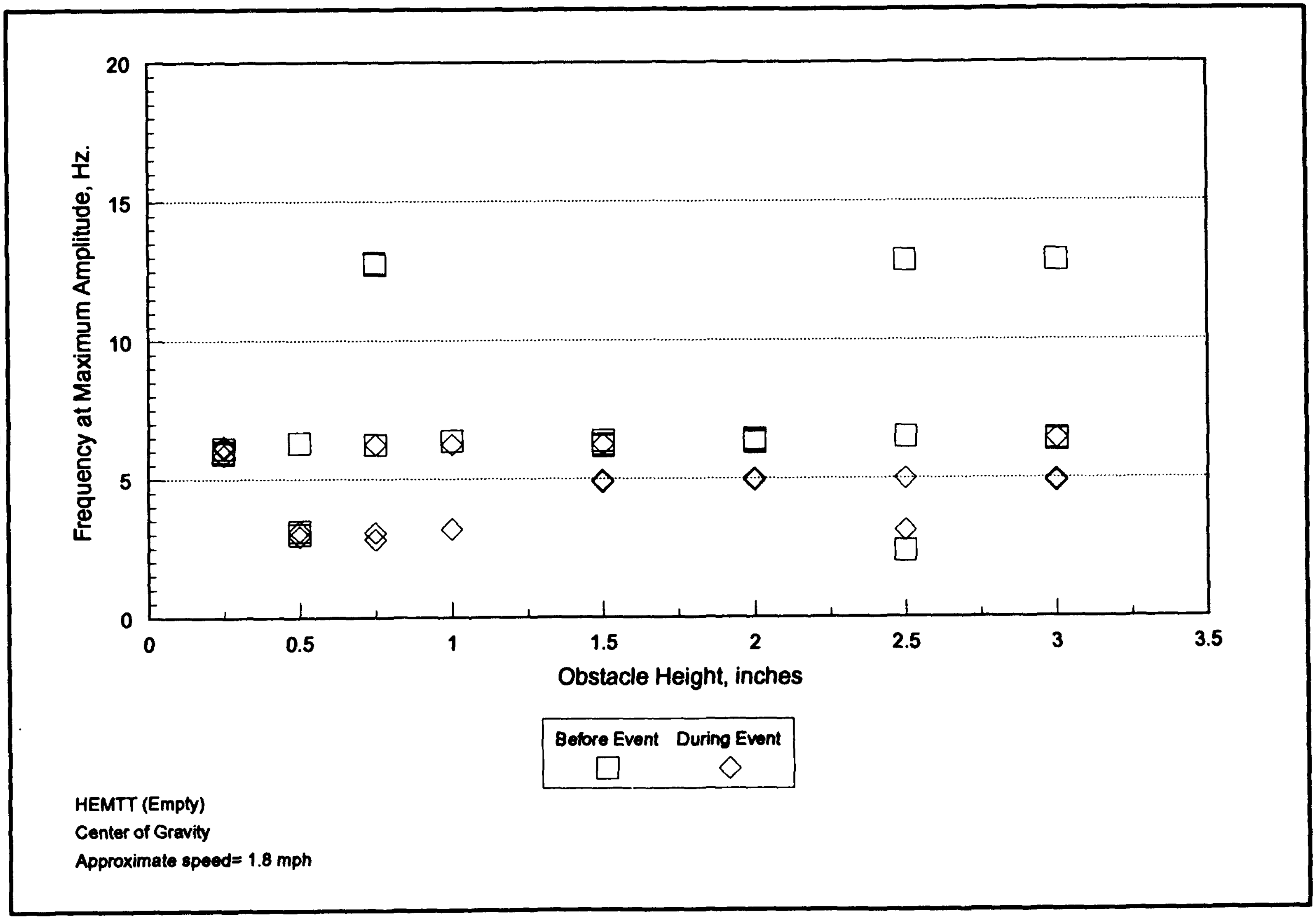

Chart B-11. Frequency at maximum amplitude versus obstacle height for c.g. at 1.8 mph (empty vehicle).

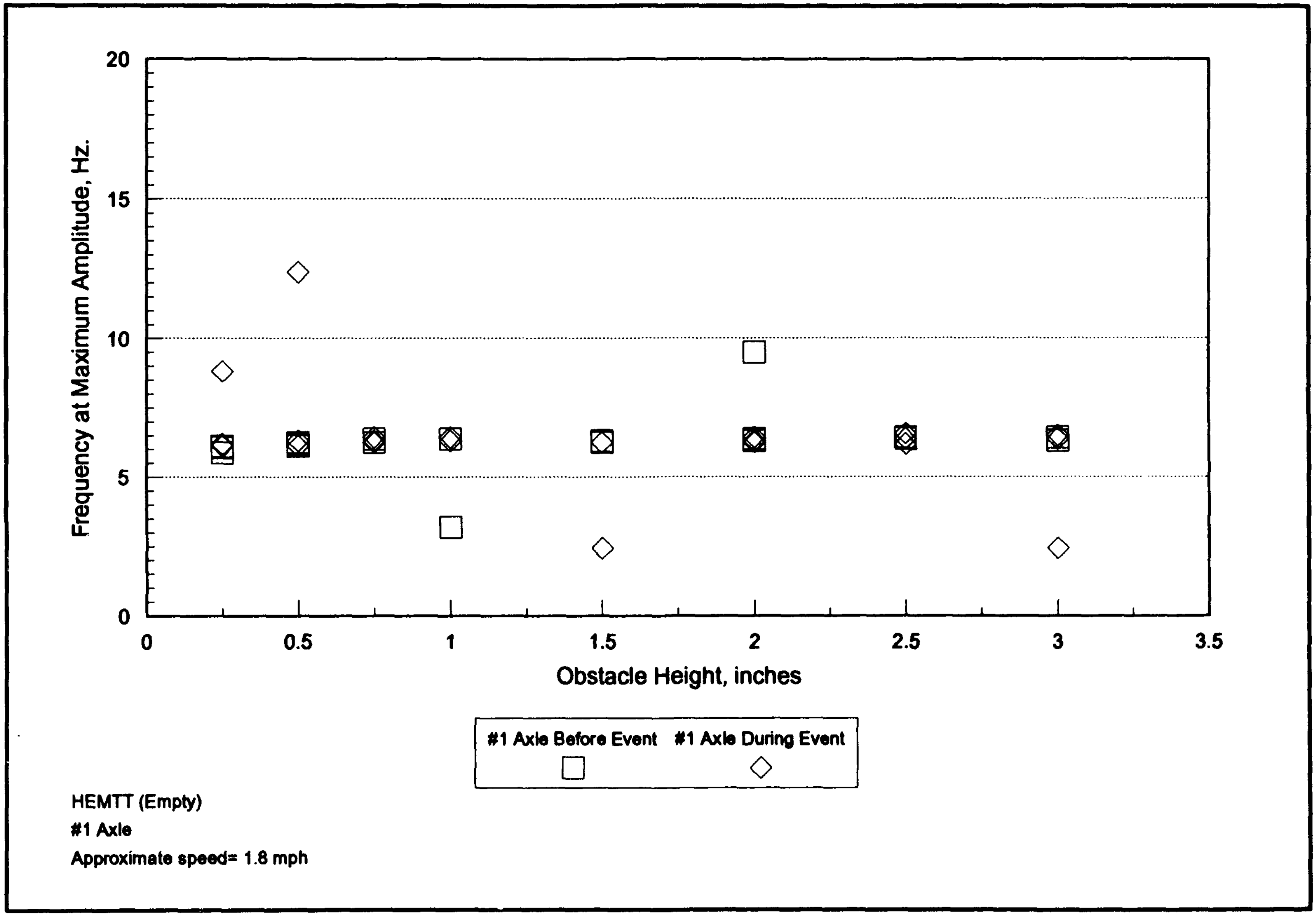

Chart B-12. Frequency at maximum amplitude versus obstacle height for axle #1 at 1.8 mph (empty vehicle).

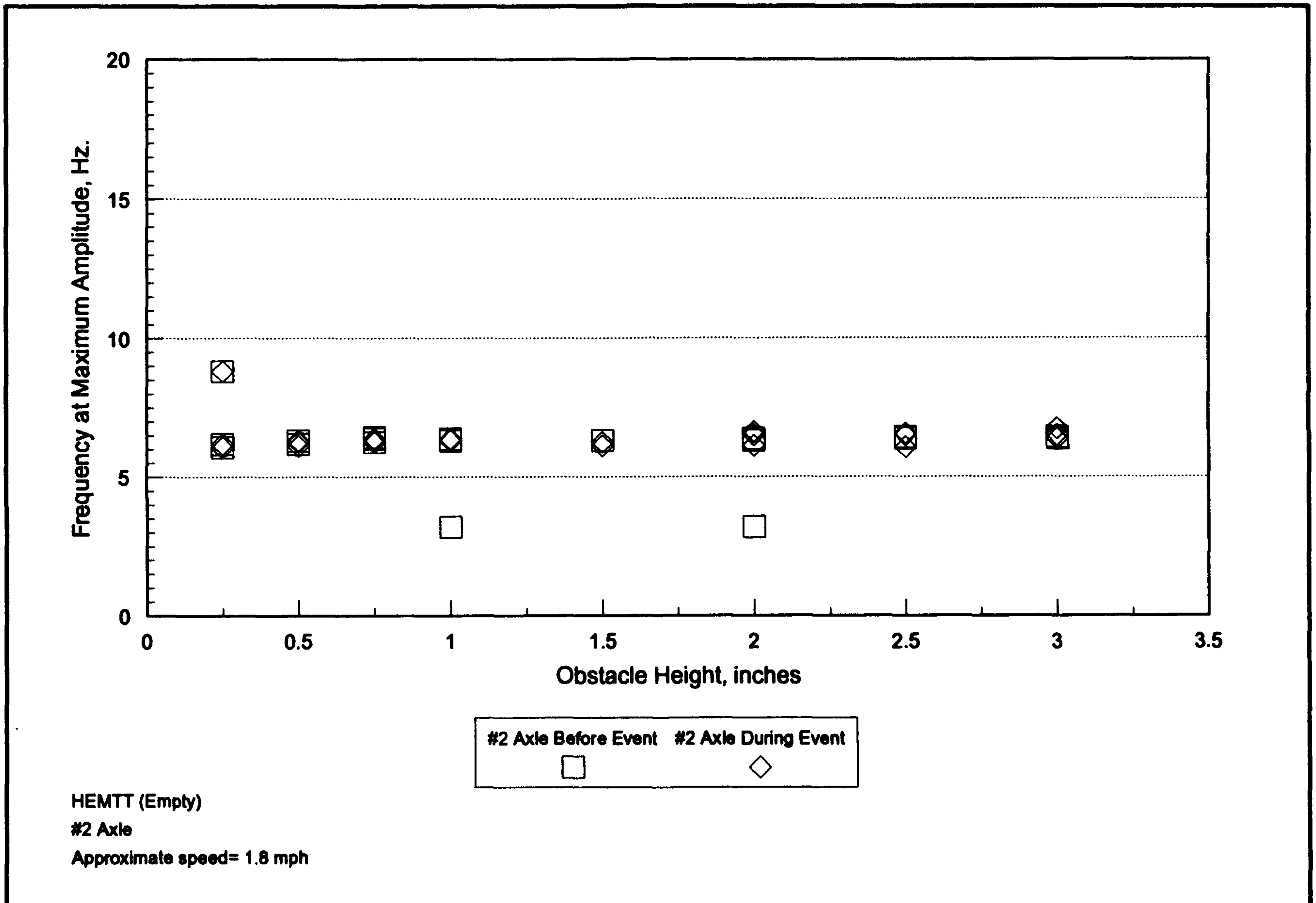

Chart B-13. Frequency at maximum amplitude versus obstacle height for axle #2 at 1.8 mph (empty vehicle).

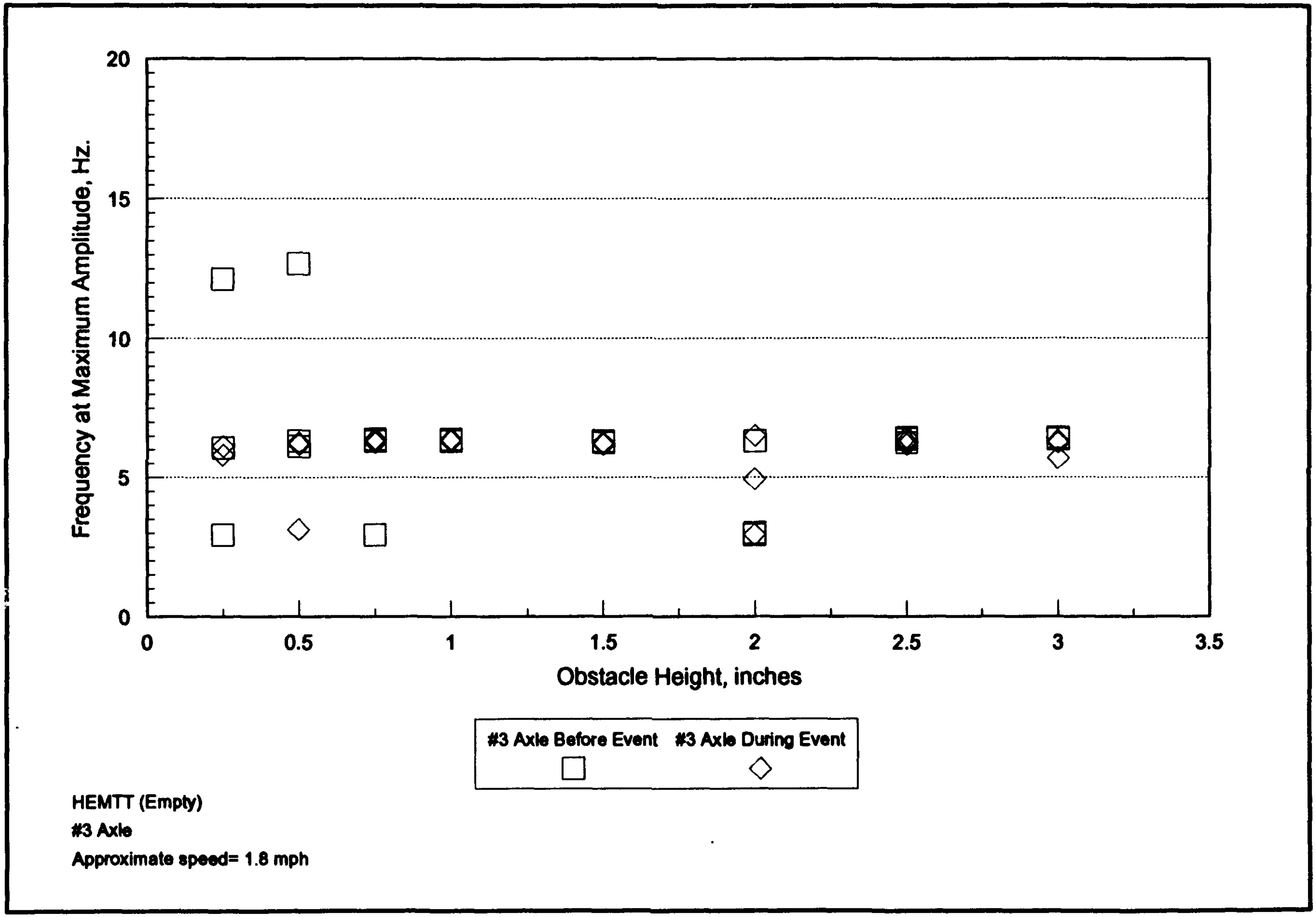

Chart B-14. Frequency at maximum amplitude versus obstacle height for axle #3 at 1.8 mph (empty vehicle).

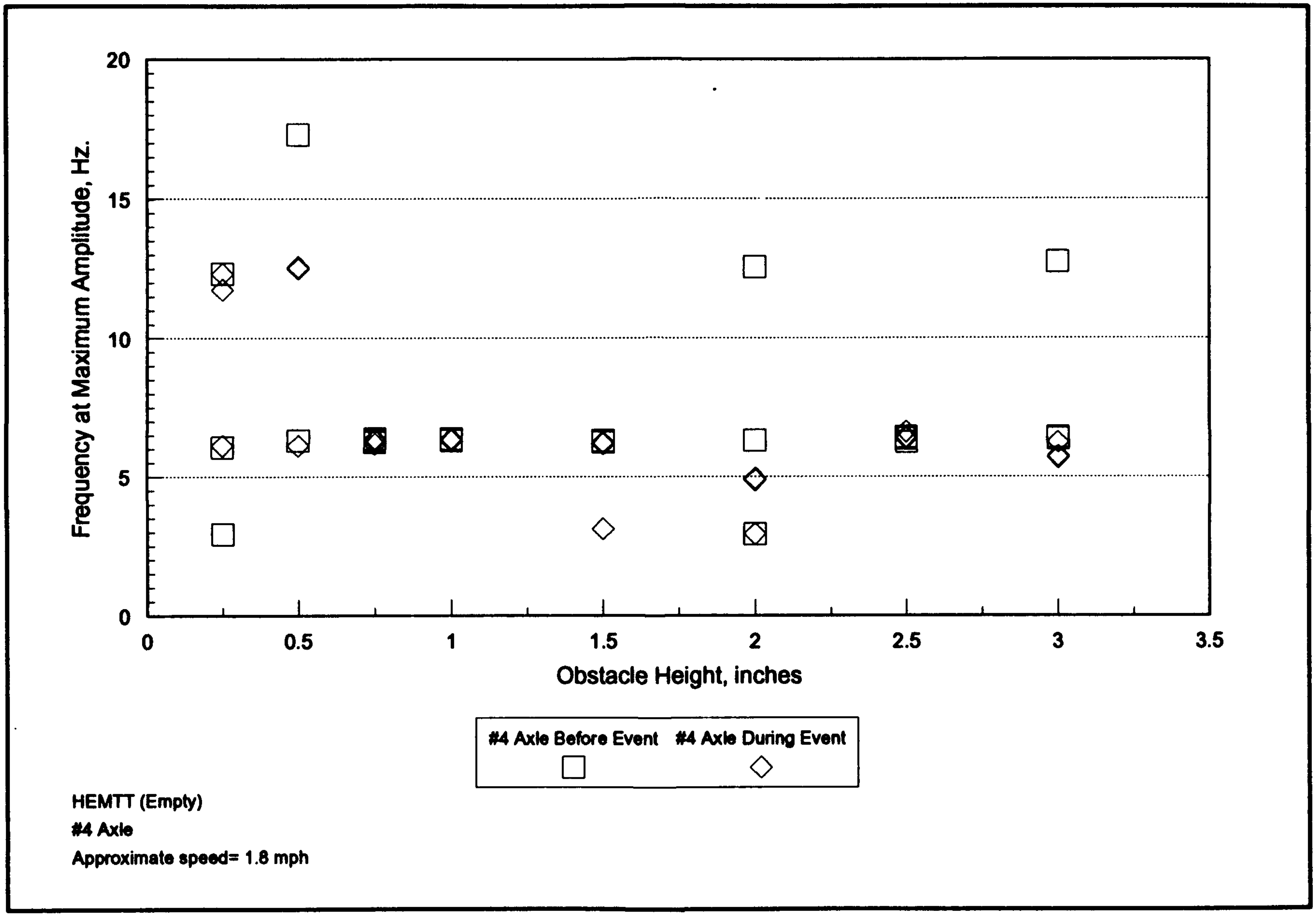

Chart B-15. Frequency at maximum amplitude versus obstacle height for axle #4 at 1.8 mph (empty vehicle).

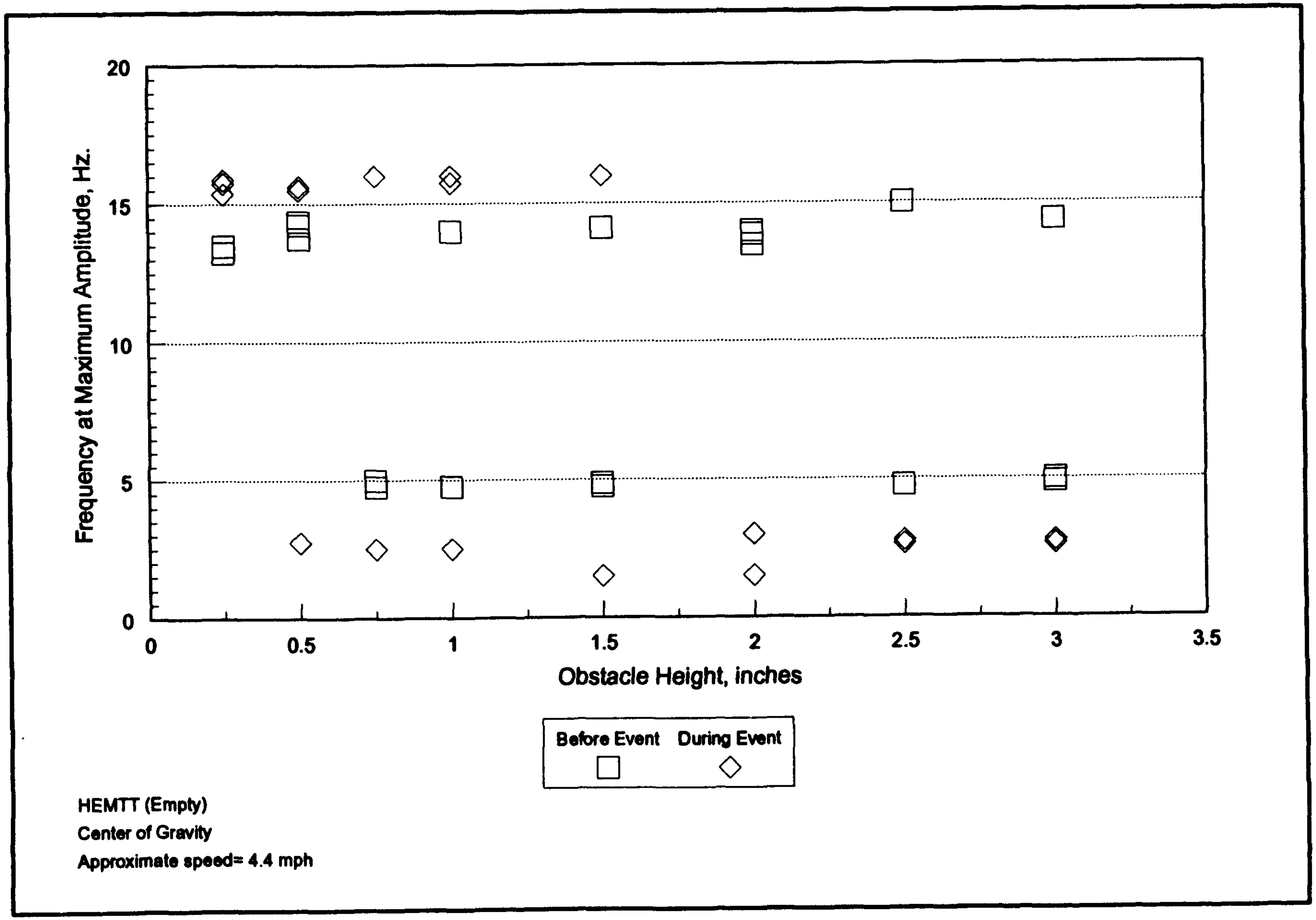

Chart B-16. Frequency at maximum amplitude versus obstacle height for c.g. at 4.4 mph (empty vehicle).

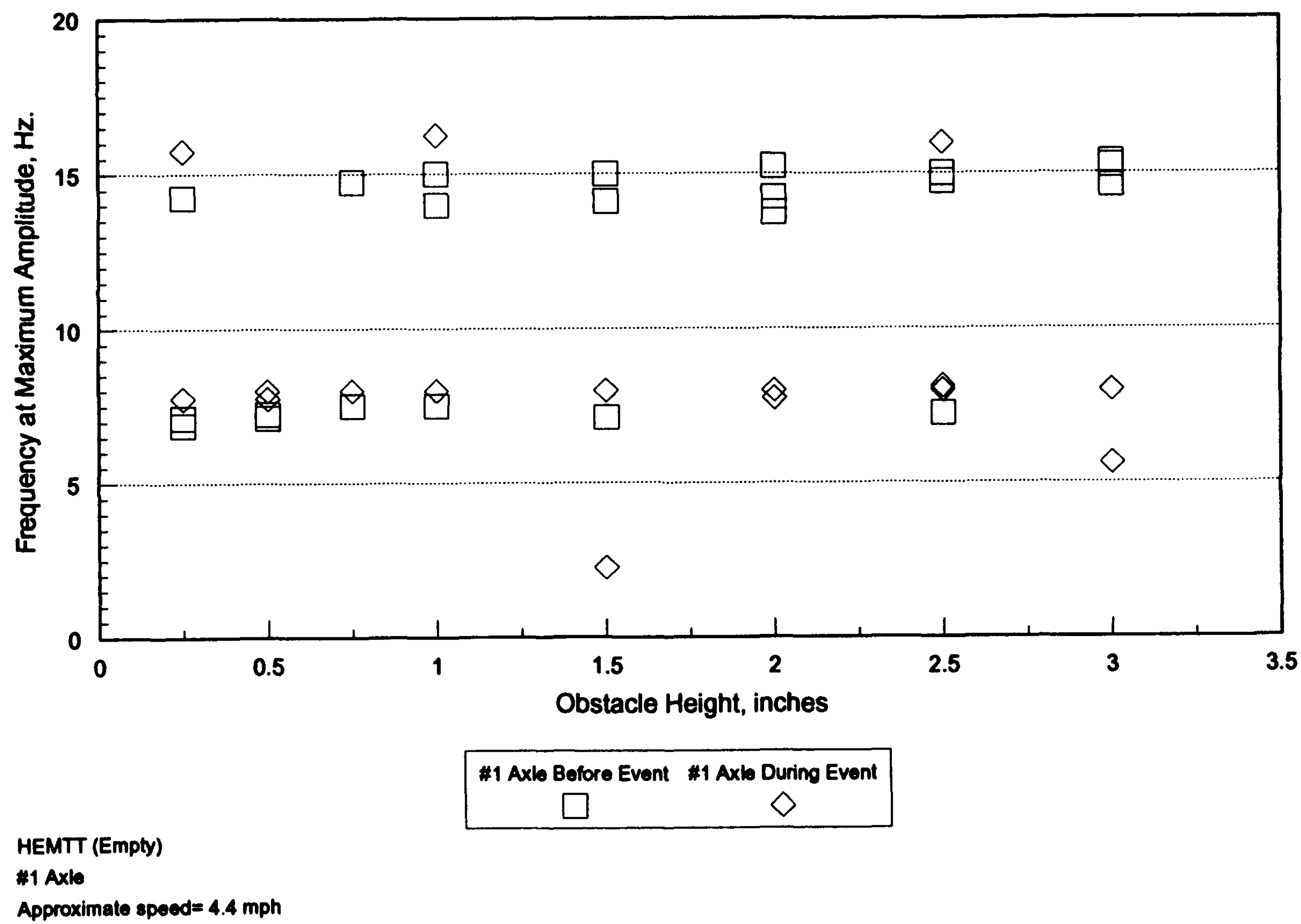

Chart B-17. Frequency at maximum amplitude versus obstacle height for axle #1 at 4.4 mph (empty vehicle).

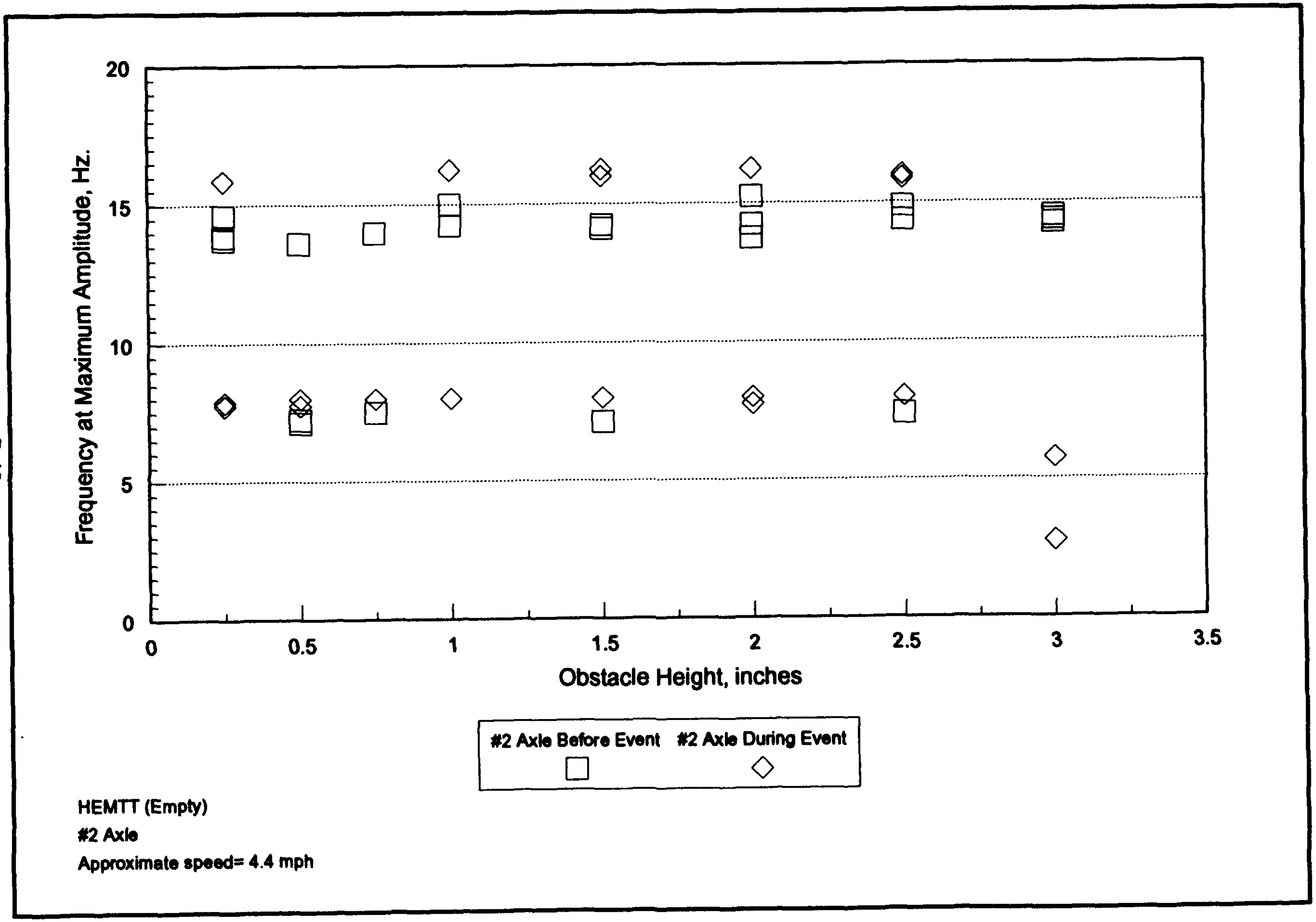

Chart B-18. Frequency at maximum amplitude versus obstacle height for axle #2 at 4.4 mph (empty vehicle).

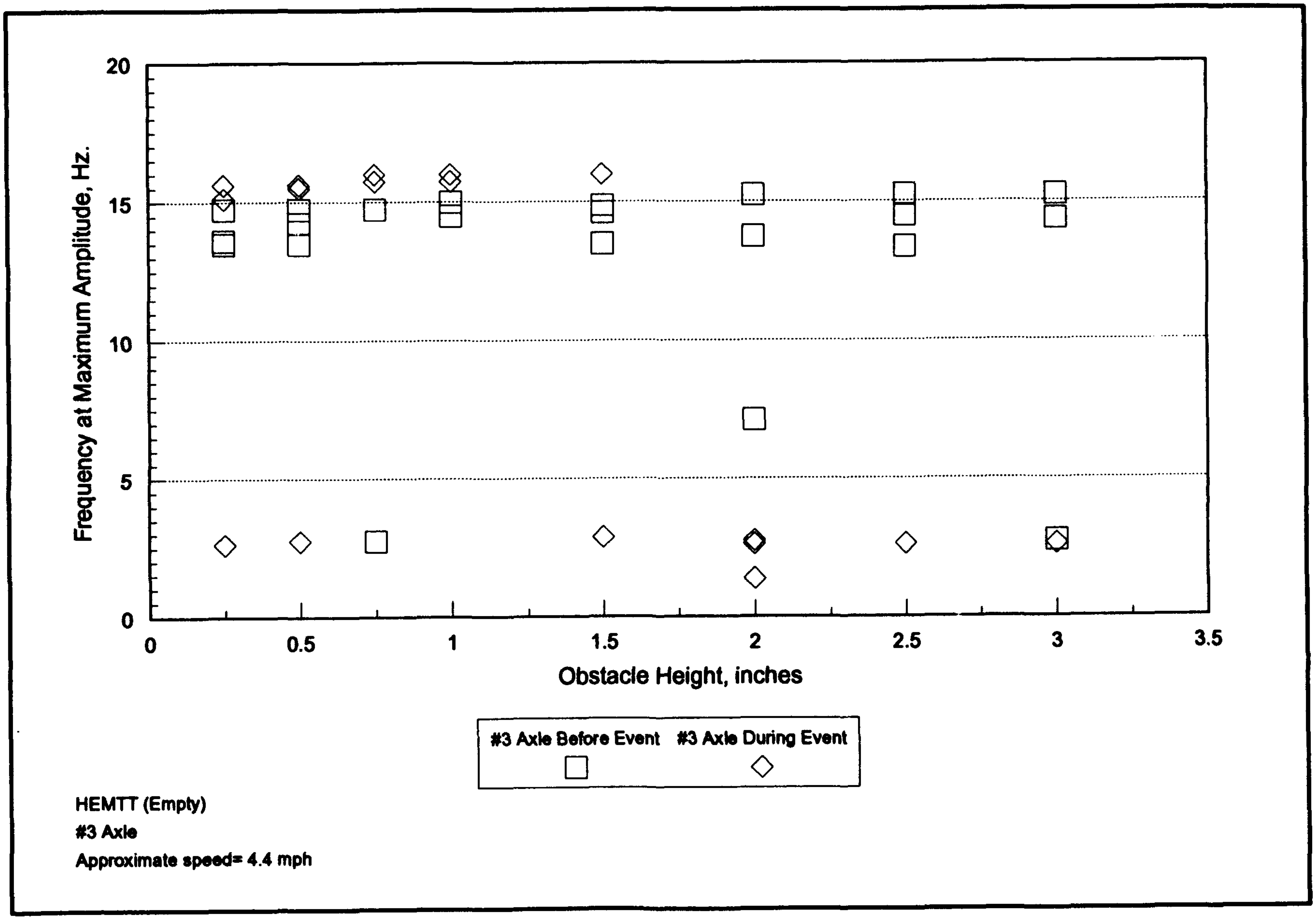

Chart B-19. Frequency at maximum amplitude versus obstacle height for axle #3 at 4.4 mph (empty vehicle).

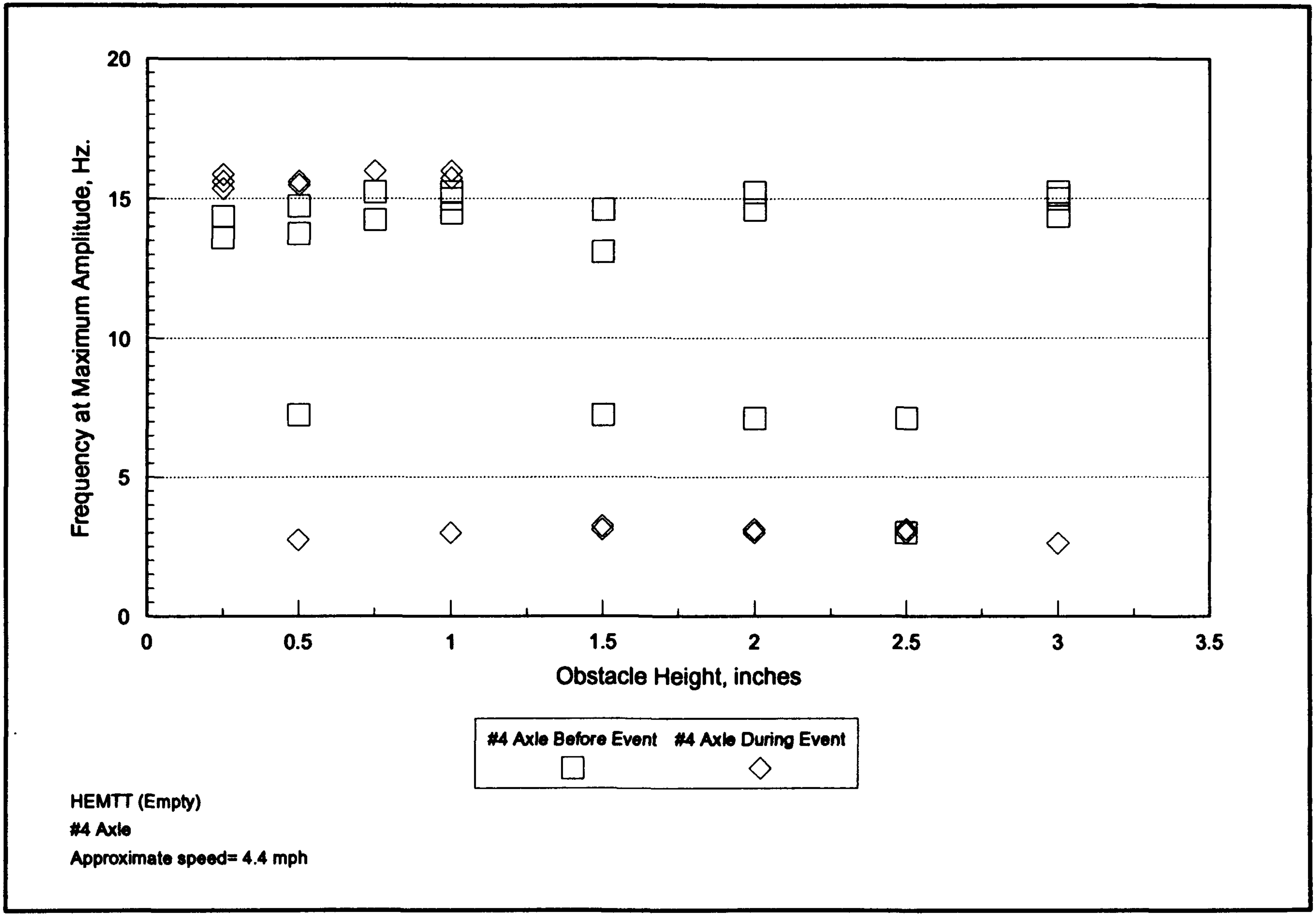

Chart B-20. Frequency at maximum amplitude versus obstacle height for axle #4 at 4.4 mph (empty vehicle).

APPENDIX C

MAXIMUM AMPLITUDE PLOTS AT DOMINANT FREQUENCY VERSUS OBSTACLE HEIGHT

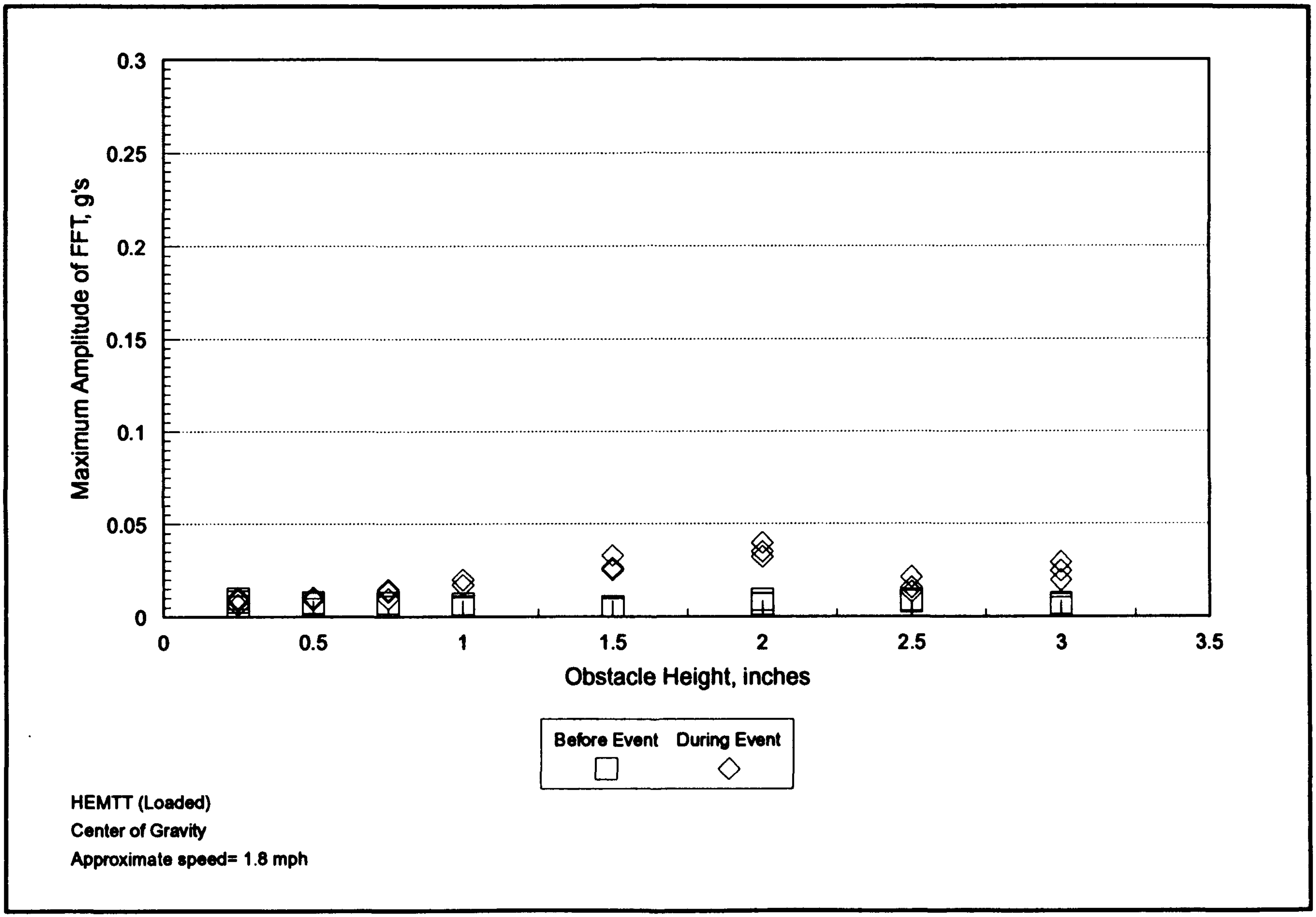

Chart C-1. Maximum amplitude of FFT versus obstacle height for c.g. at 1.8 mph (loaded vehicle).

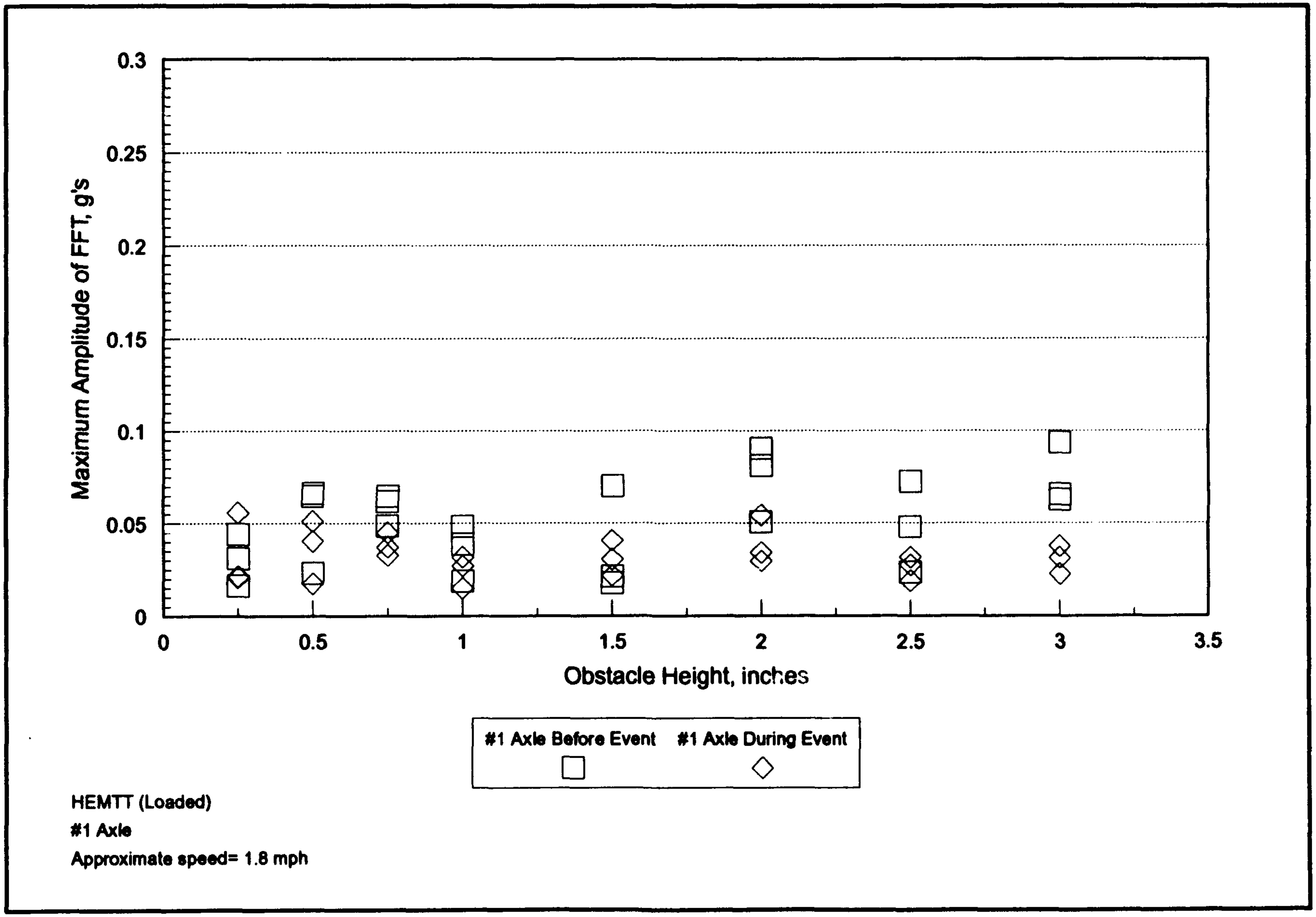

Chart C-2. Maximum amplitude of FFT versus obstacle height for axle #1 at 1.8 mph (loaded vehicle).

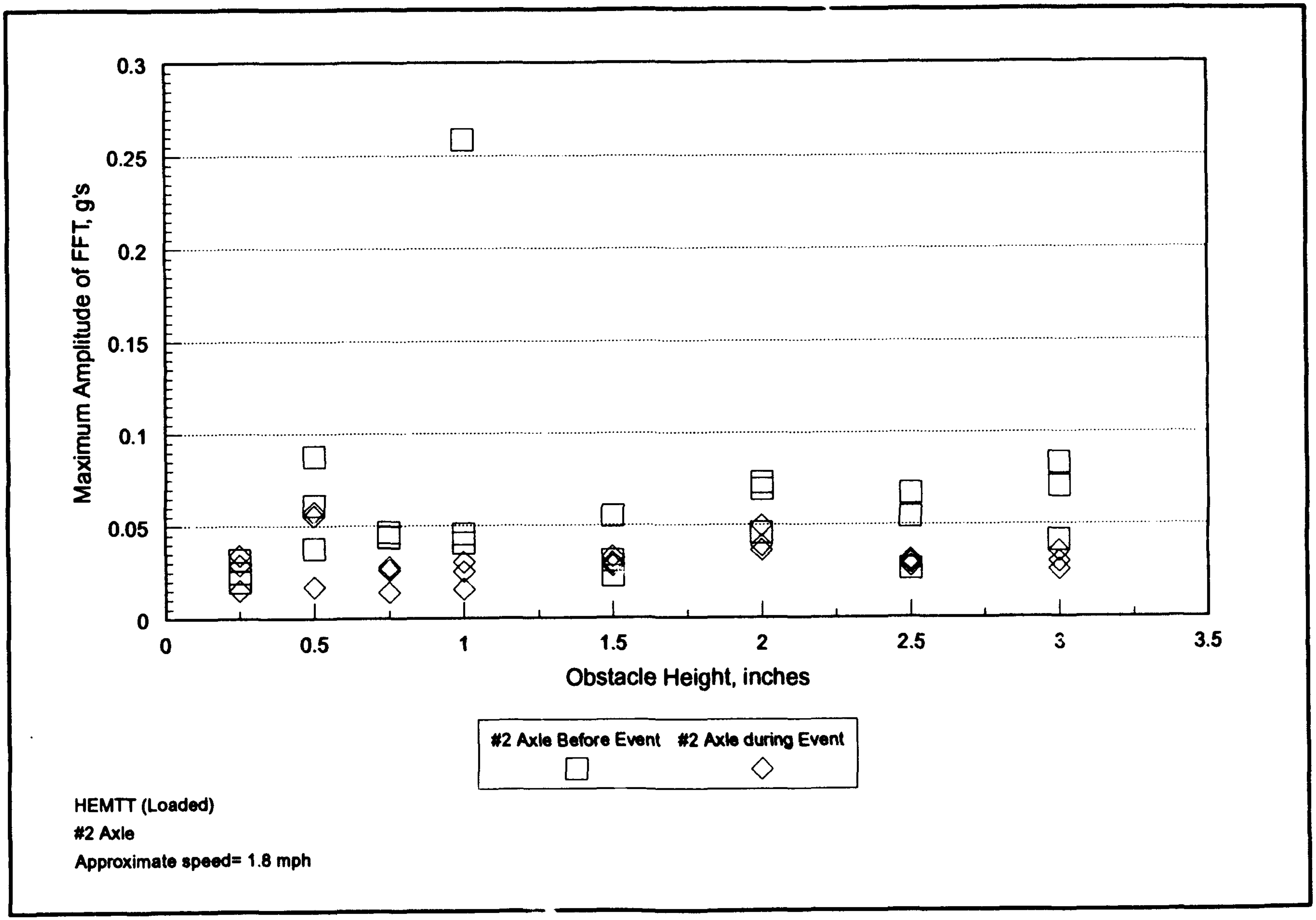

Chart C-3. Maximum amplitude of FFT versus obstacle height for axle #2 at 1.8 mph (loaded vehicle).

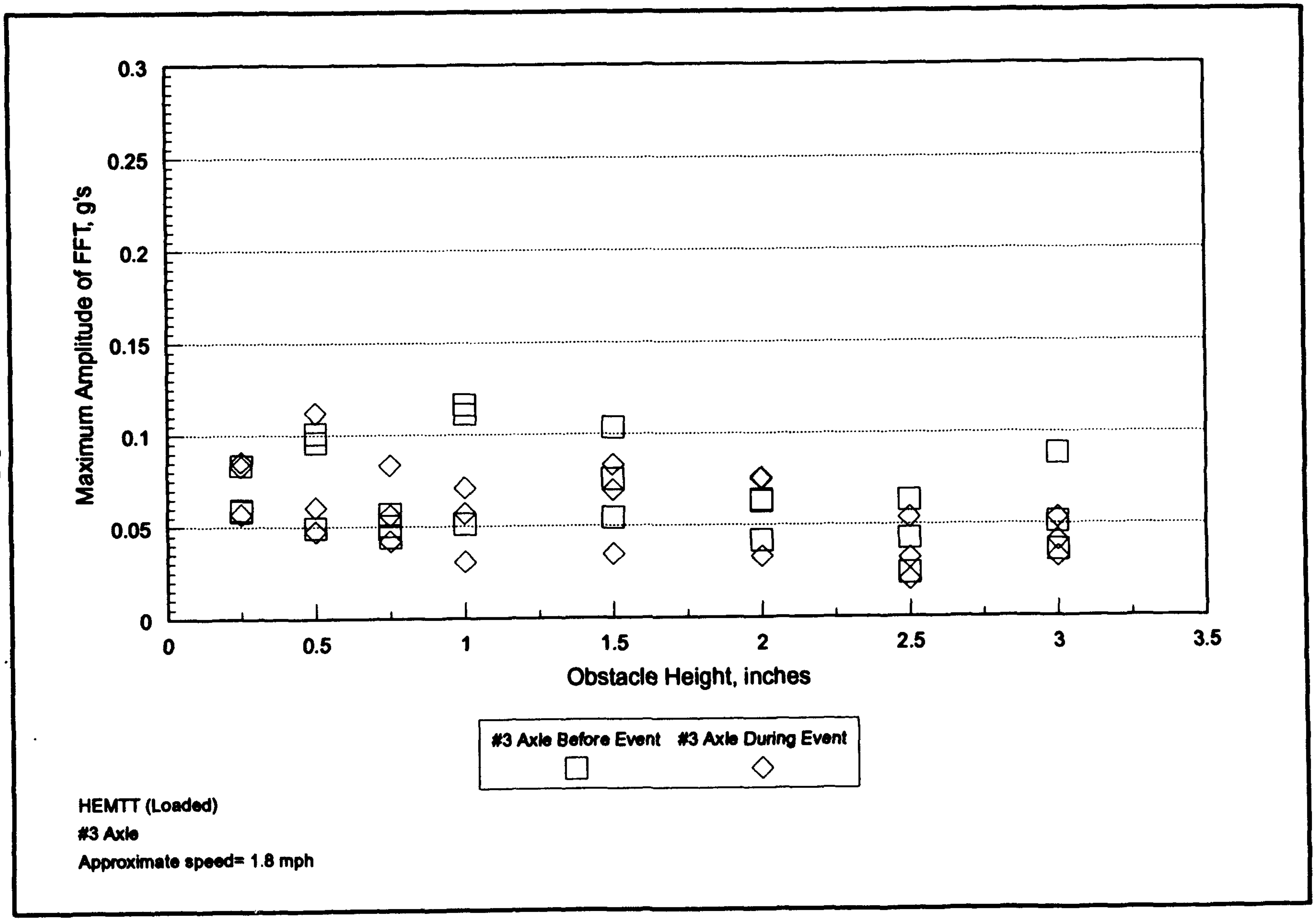

Chart C-4. Maximum amplitude of FFT versus obstacle height for axle #3 at 1.8 mph (loaded vehicle).

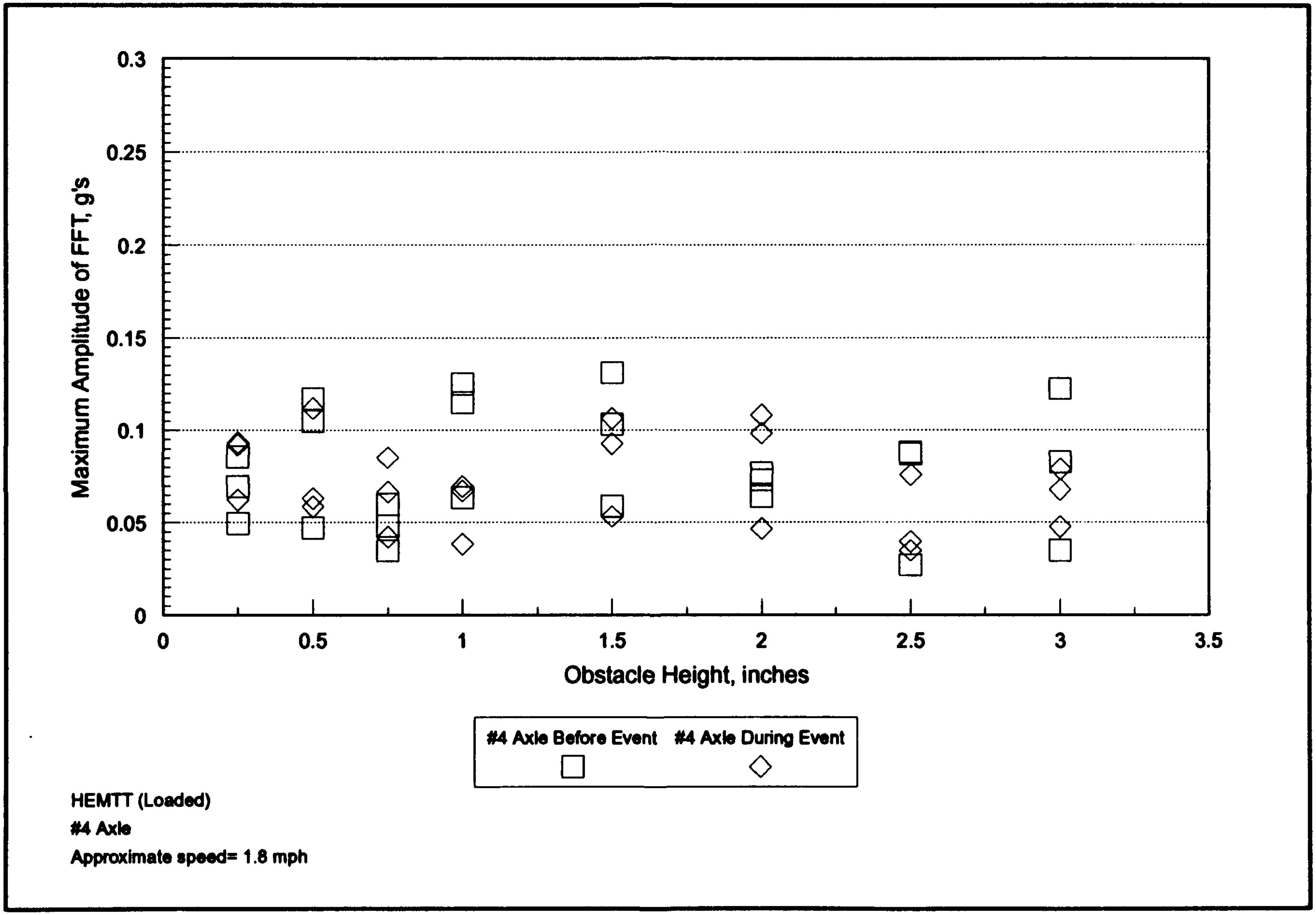

Chart C-5. Maximum amplitude of FFT versus obstacle height for axle #4 at 1.8 mph (loaded vehicle).

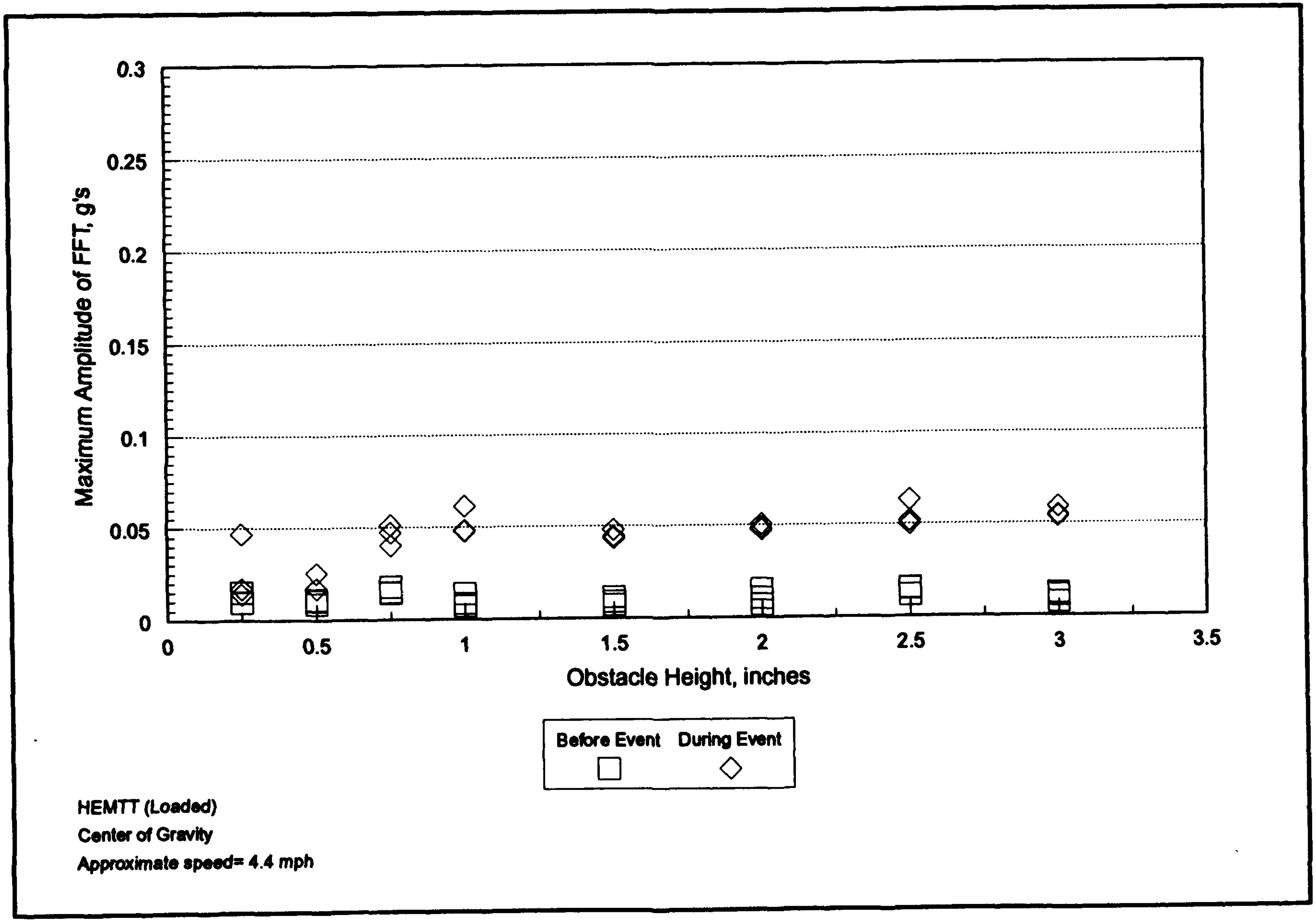

Chart C-6. Maximum amplitude of FFT versus obstacle height for c.g. at 4.4 mph (loaded vehicle).

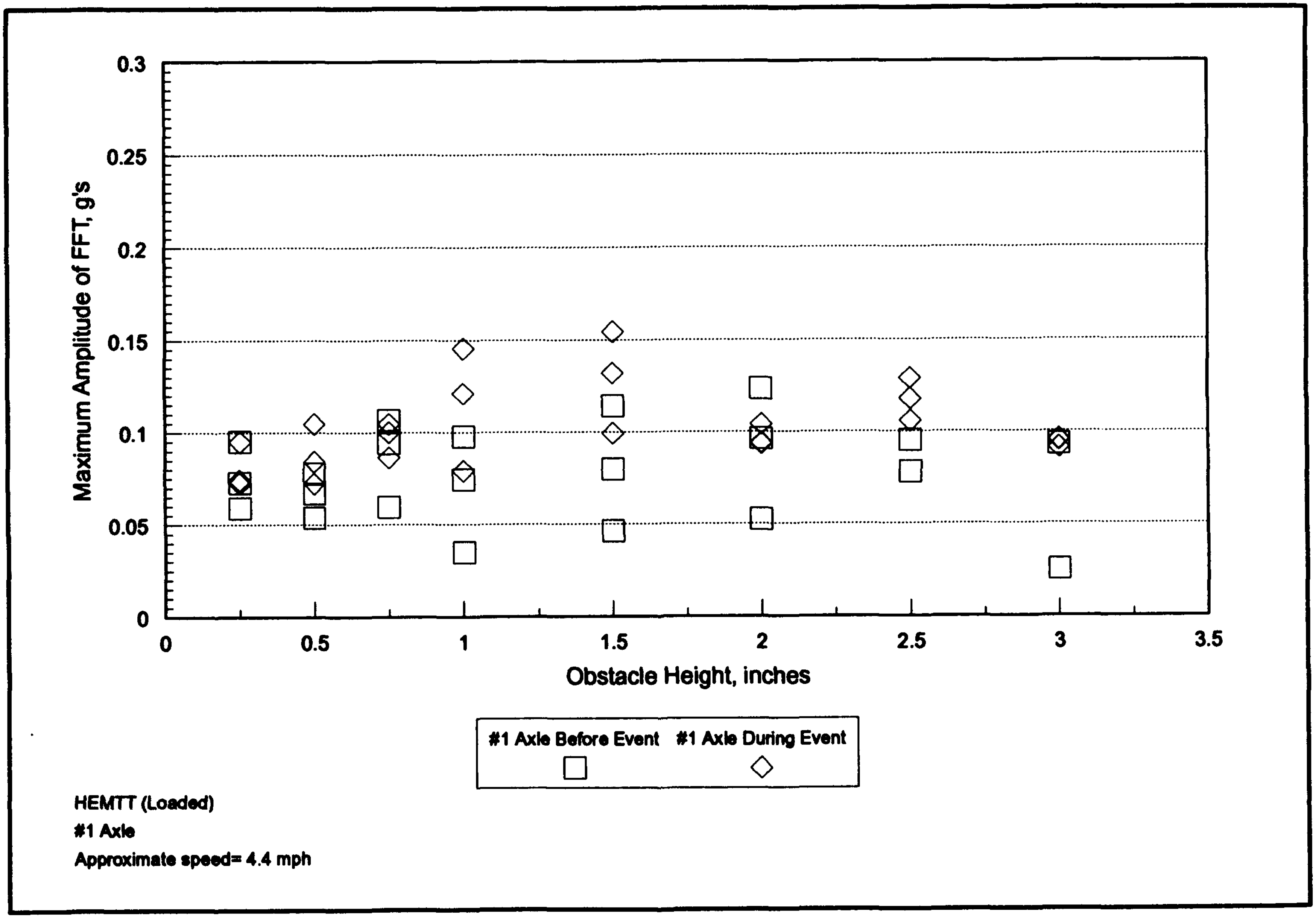

Chart C-7. Maximum amplitude of FFT versus obstacle height for axle #1 at 4.4 mph (loaded vehicle).

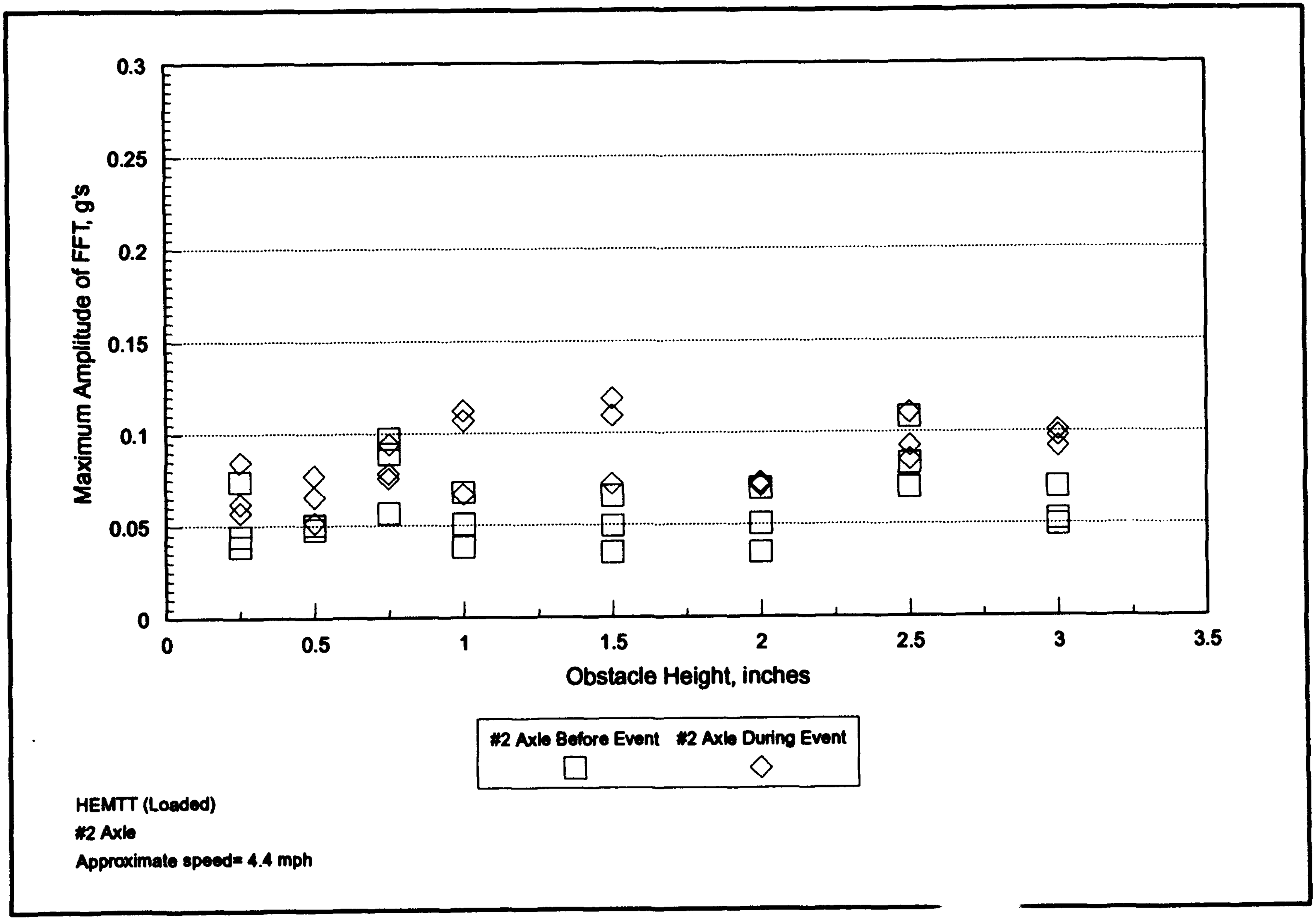

Chart C-8. Maximum amplitude of FFT versus obstacle height for axle #2 at 4.4 mph (loaded vehicle).

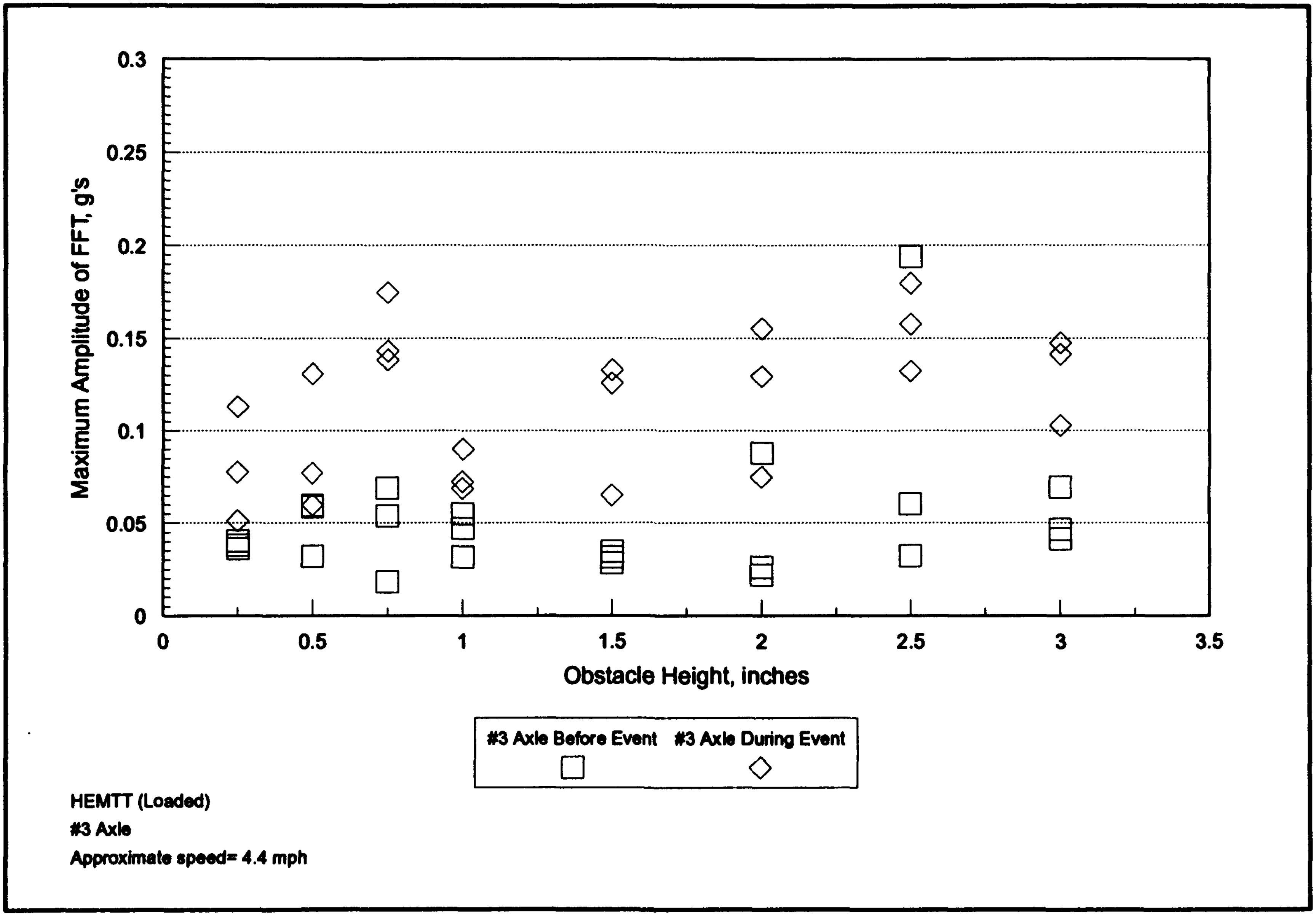

Chart C-9. Maximum amplitude of FFT versus obstacle height for axle #3 at 4.4 mph (loaded vehicle).

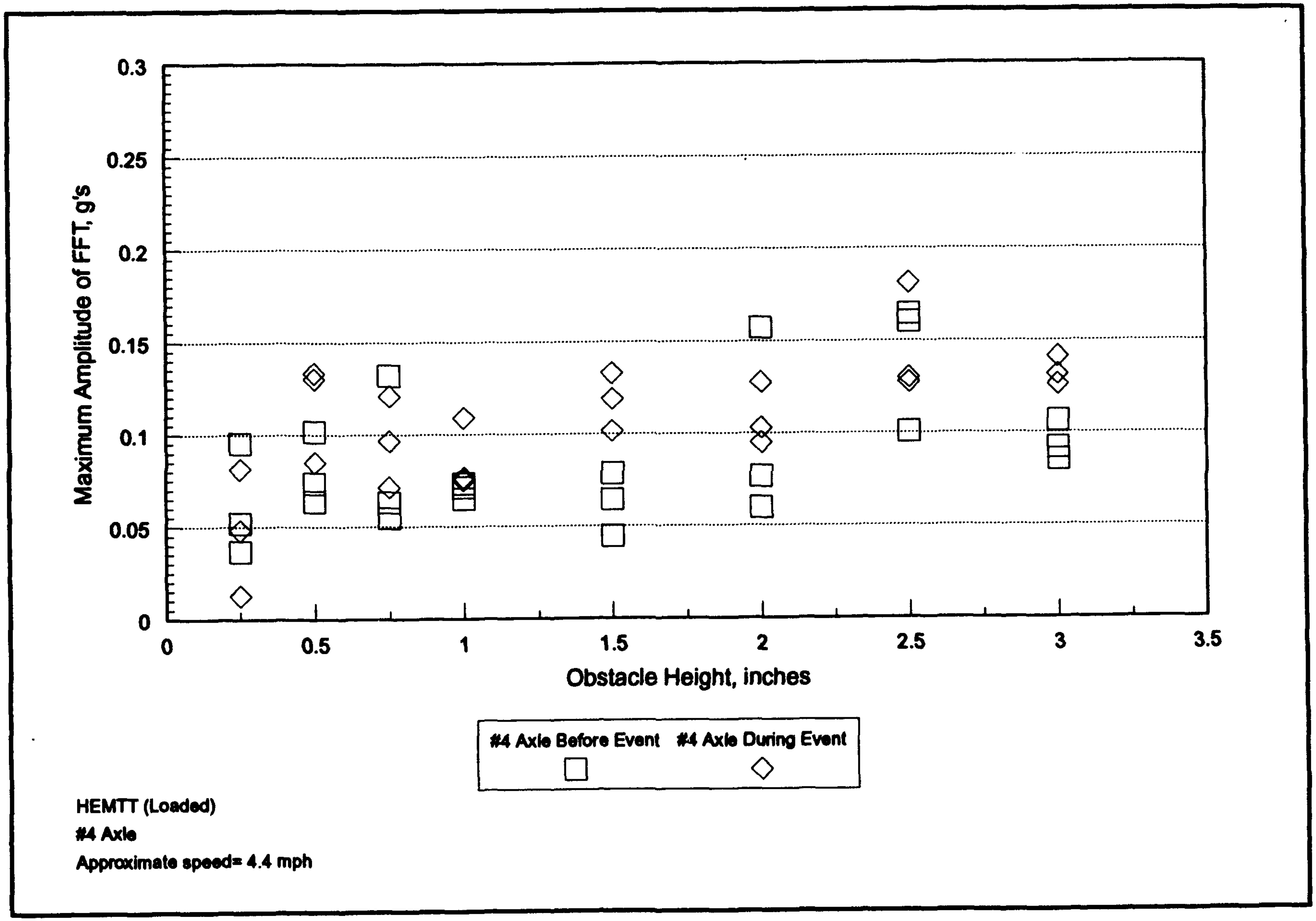

Chart C-10. Maximum amplitude of FFT versus obstacle height for axle #4 at 4.4 mph (loaded vehicle).

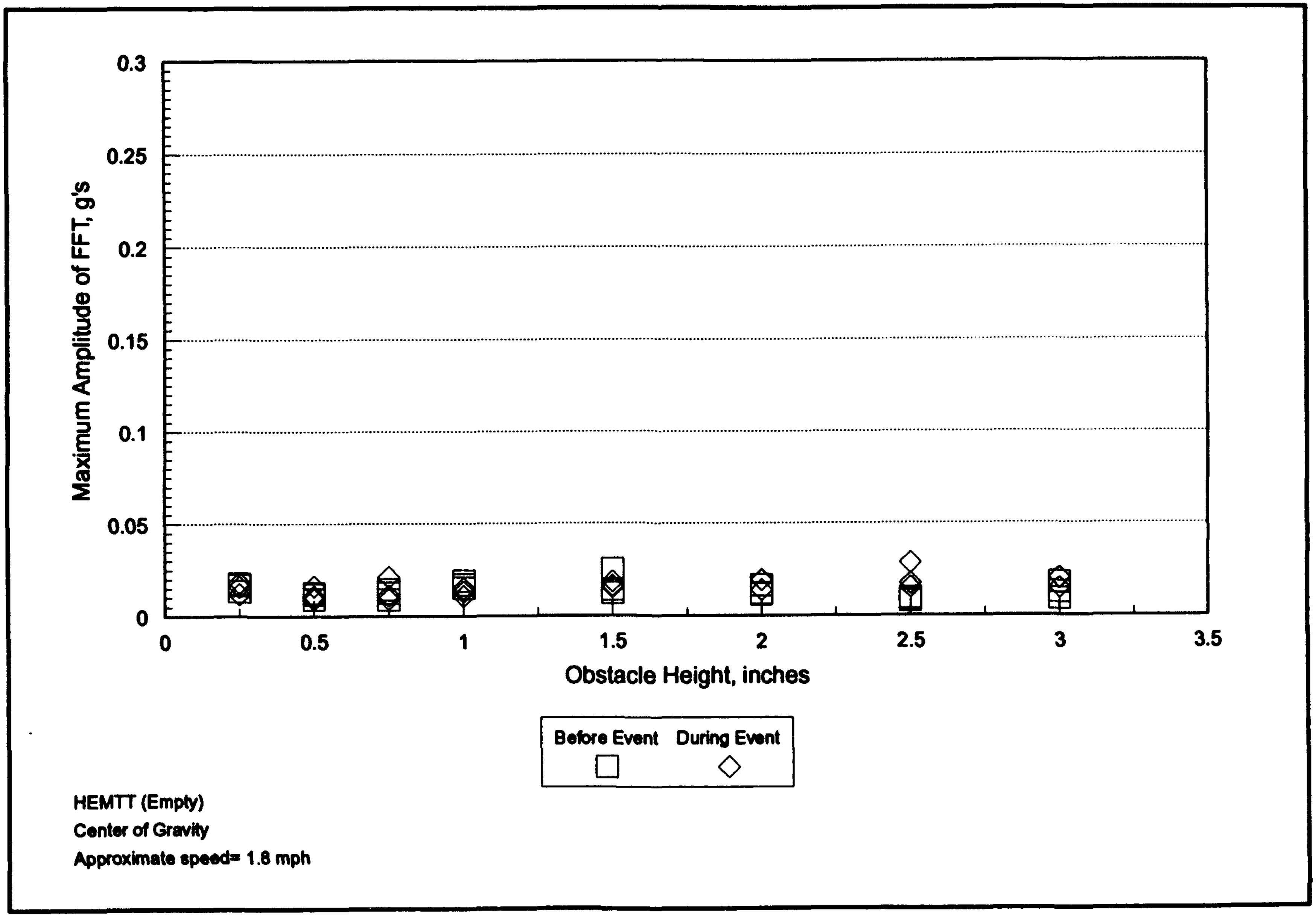

Chart C-11. Maximum amplitude of FFT versus obstacle height for c.g. at 1.8 mph (empty vehicle).

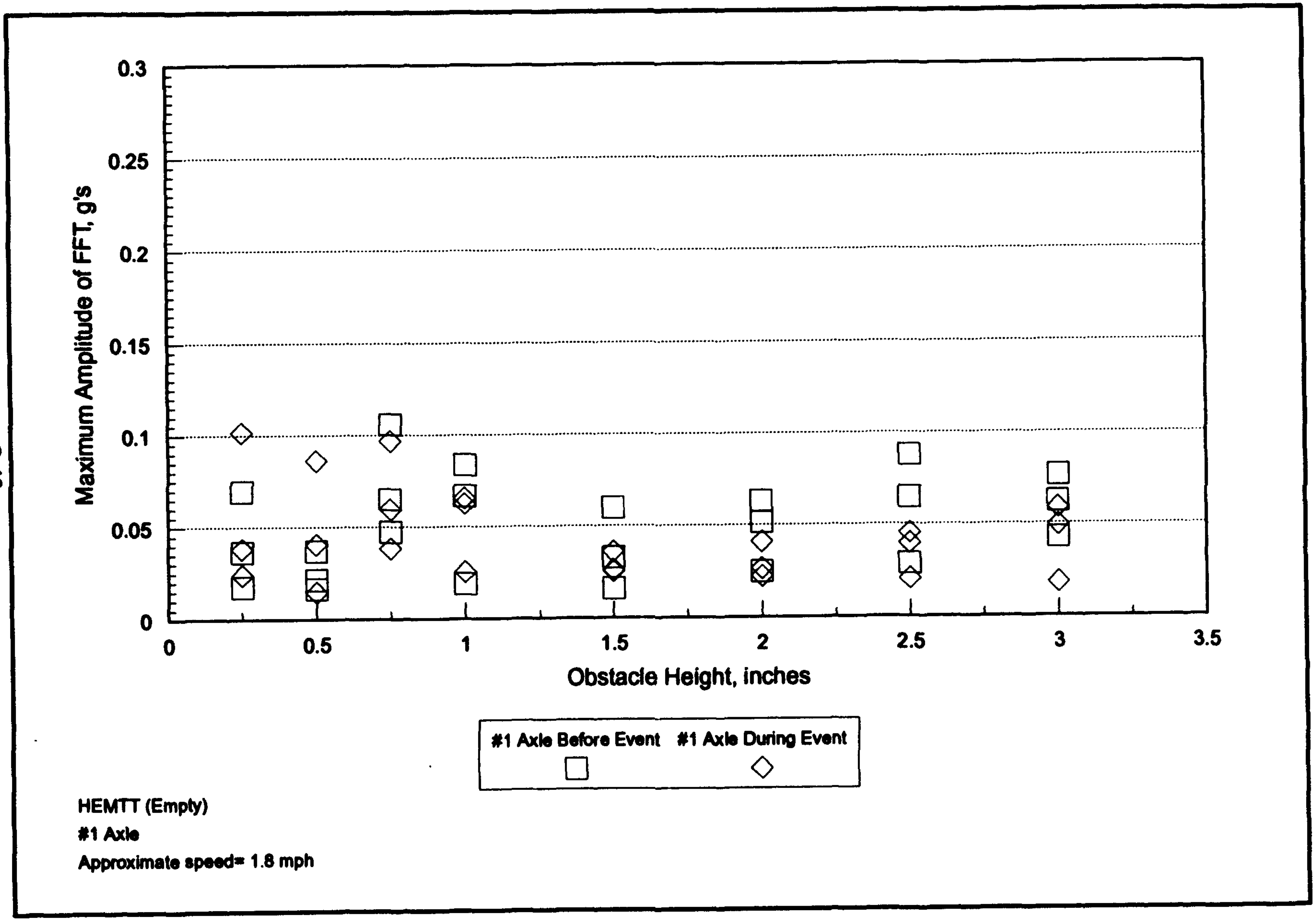

Chart C-12. Maximum amplitude of FFT versus obstacle height for axle #1 at 1.8 mph (empty vehicle).

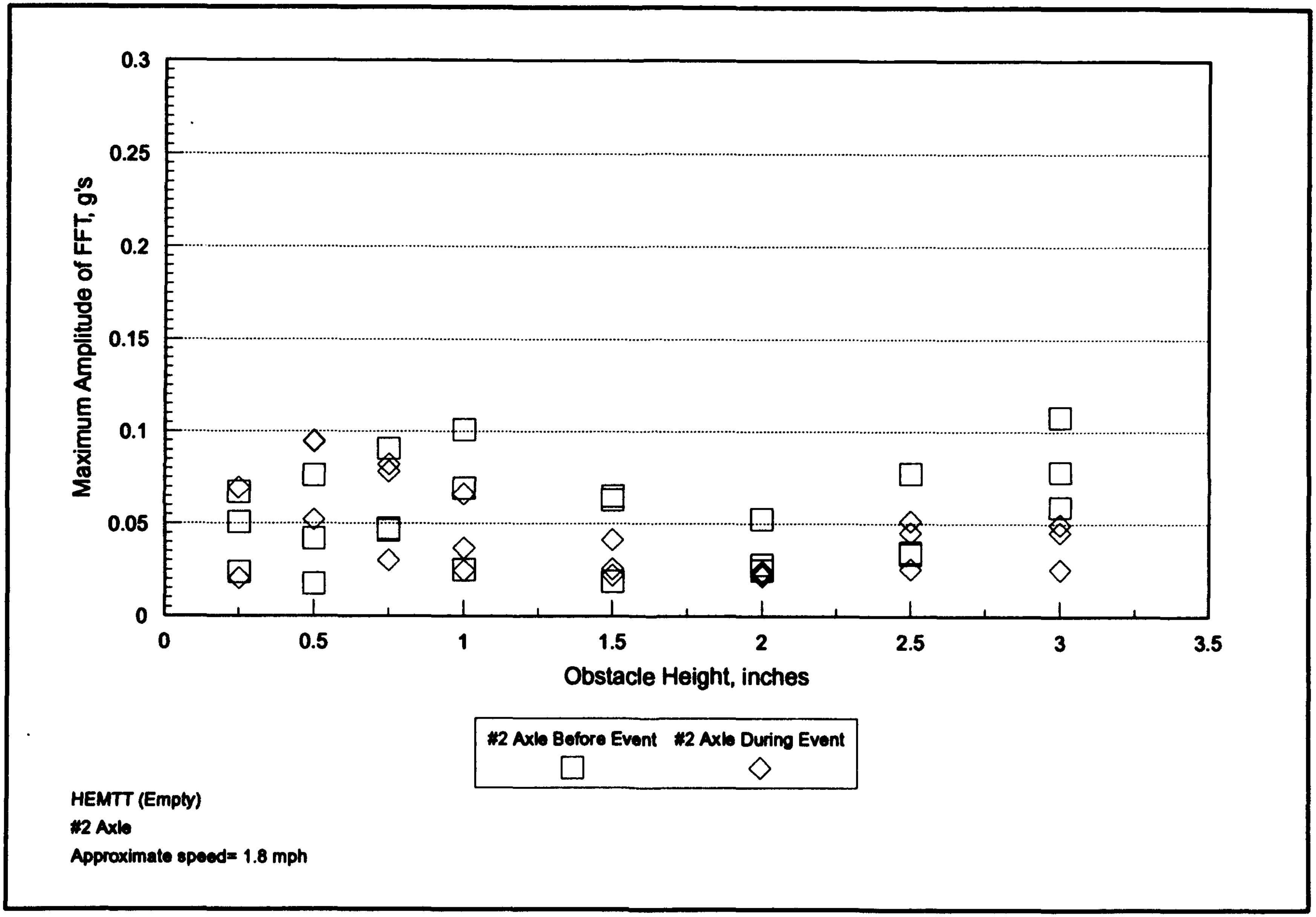

Chart C-13. Maximum amplitude of FFT versus obstacle height for axle #2 at 1.8 mph (empty vehicle).

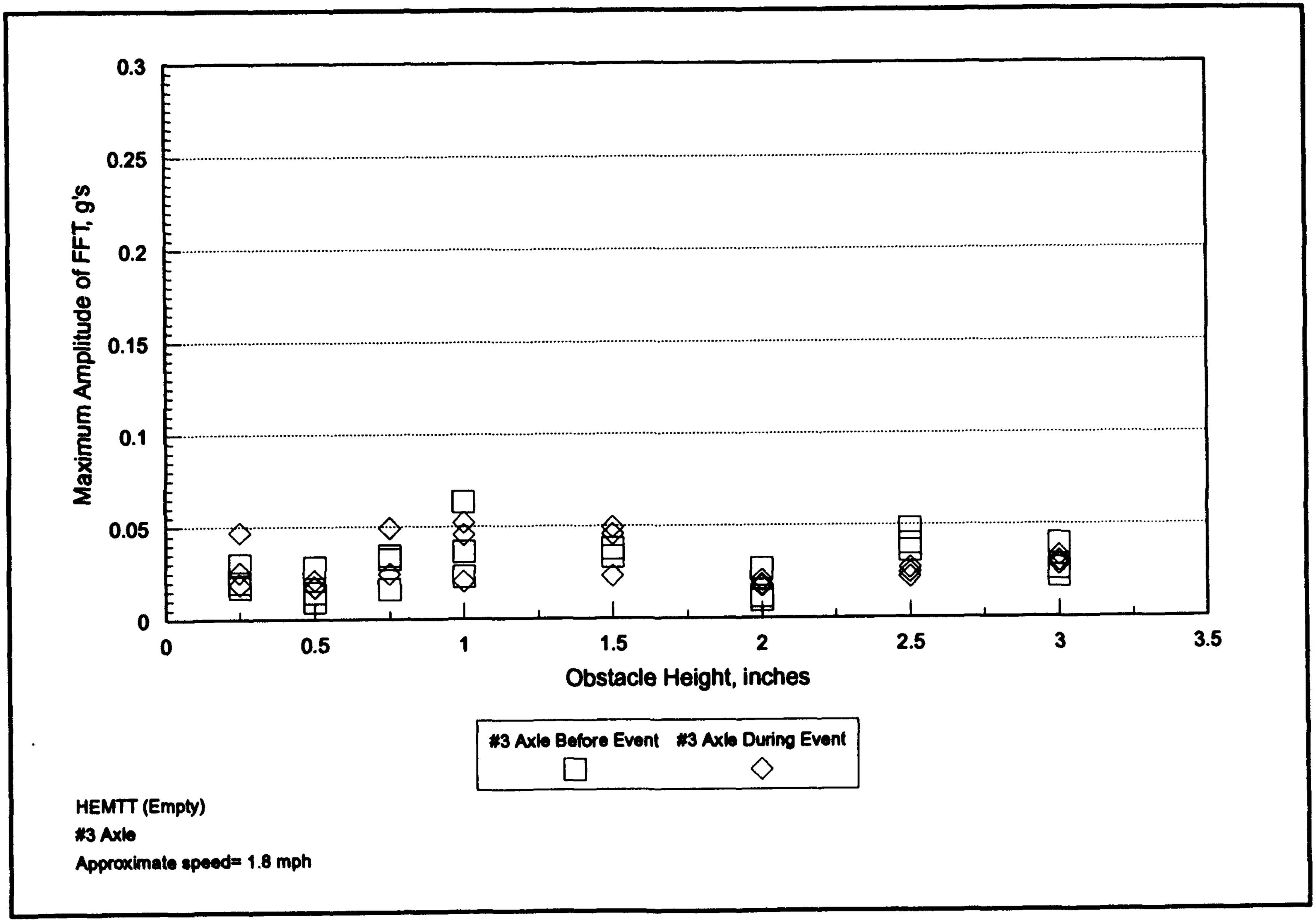

Chart C-14. Maximum amplitude of FFT versus obstacle height for axle #3 at 1.8 mph (empty vehicle).

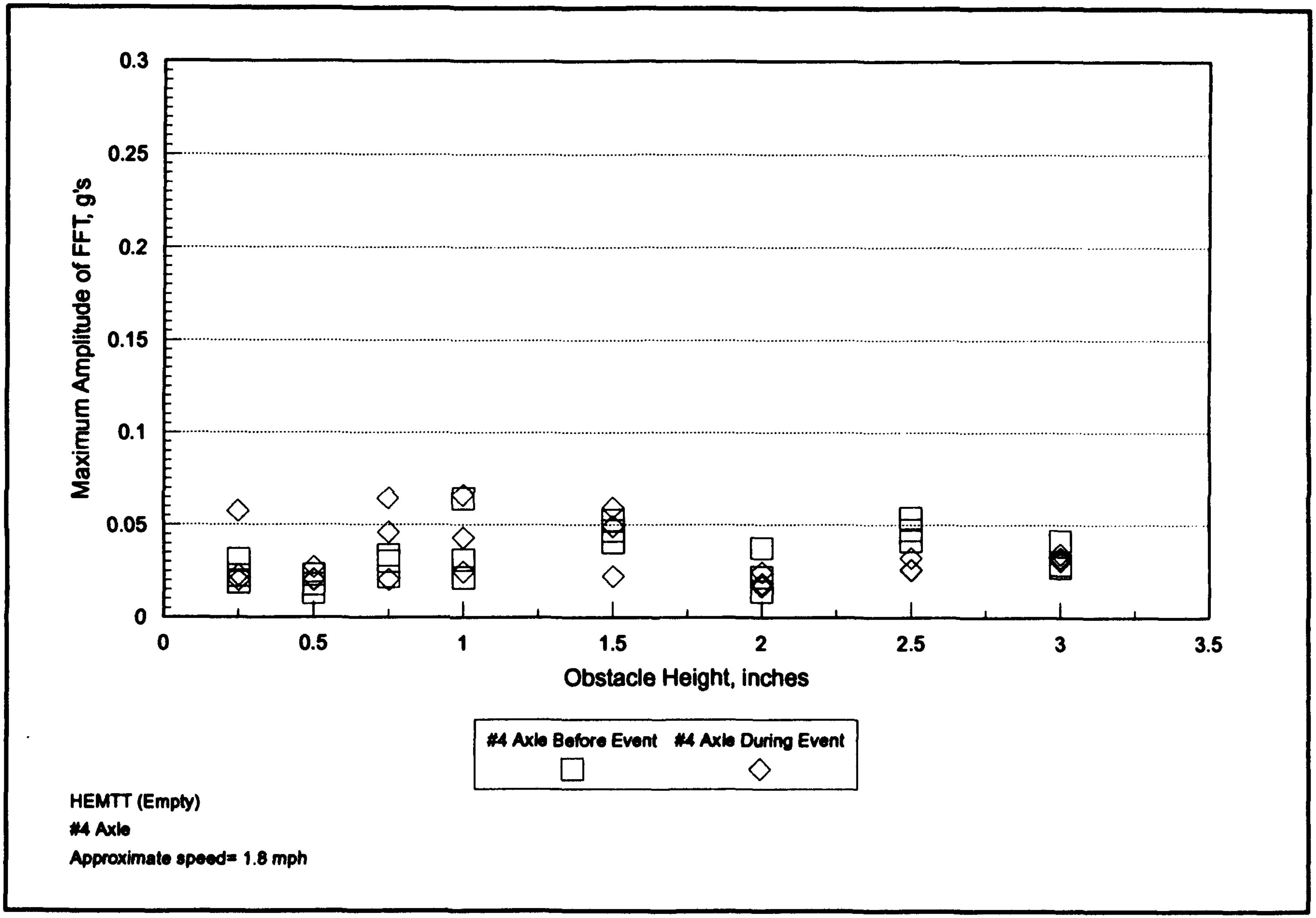

Chart C-15. Maximum amplitude of FFT versus obstacle height for axle #4 at 1.8 mph (empty vehicle).

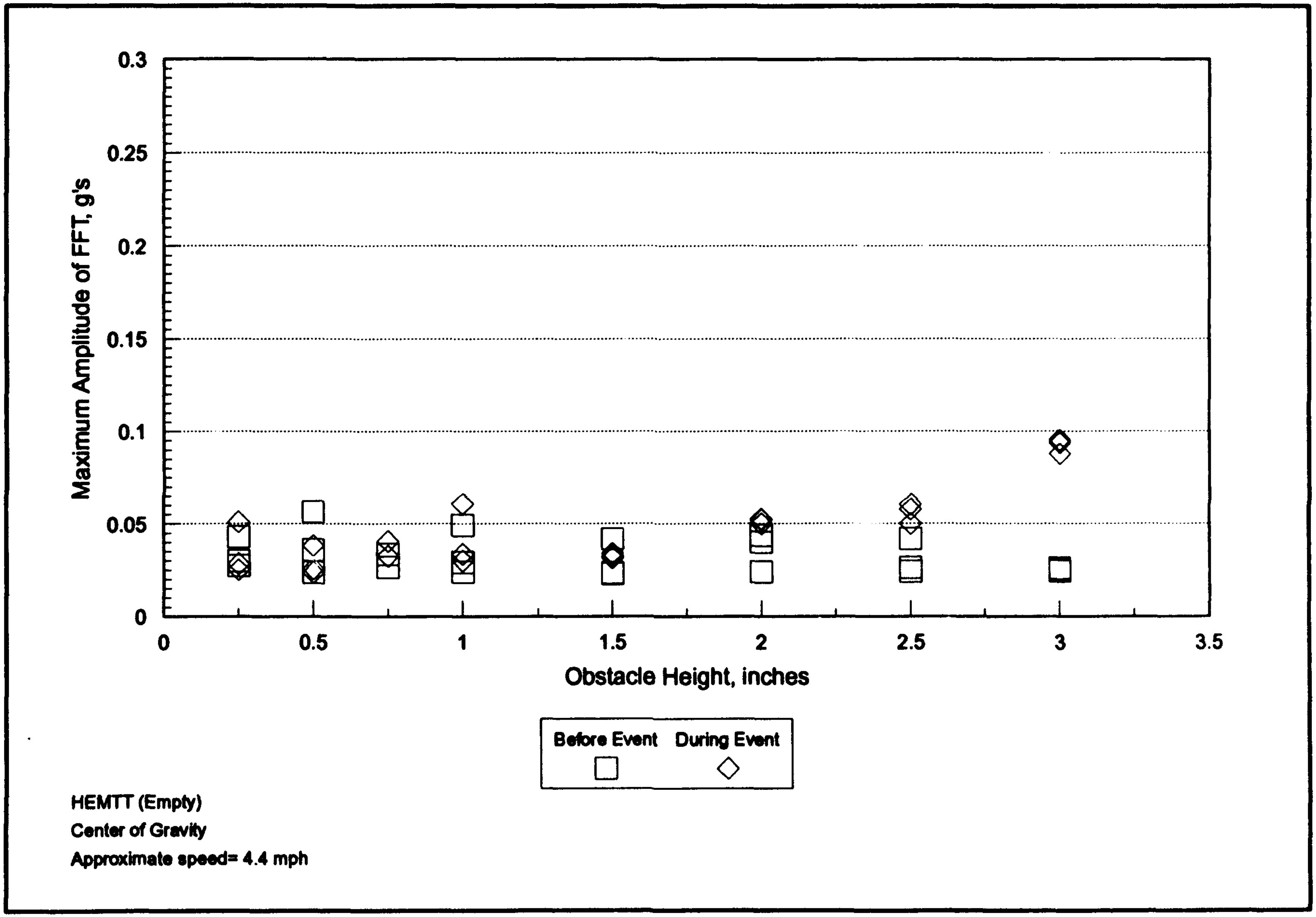

Chart C-16. Maximum amplitude of FFT versus obstacle height for c.g. at 4.4 mph (empty vehicle).

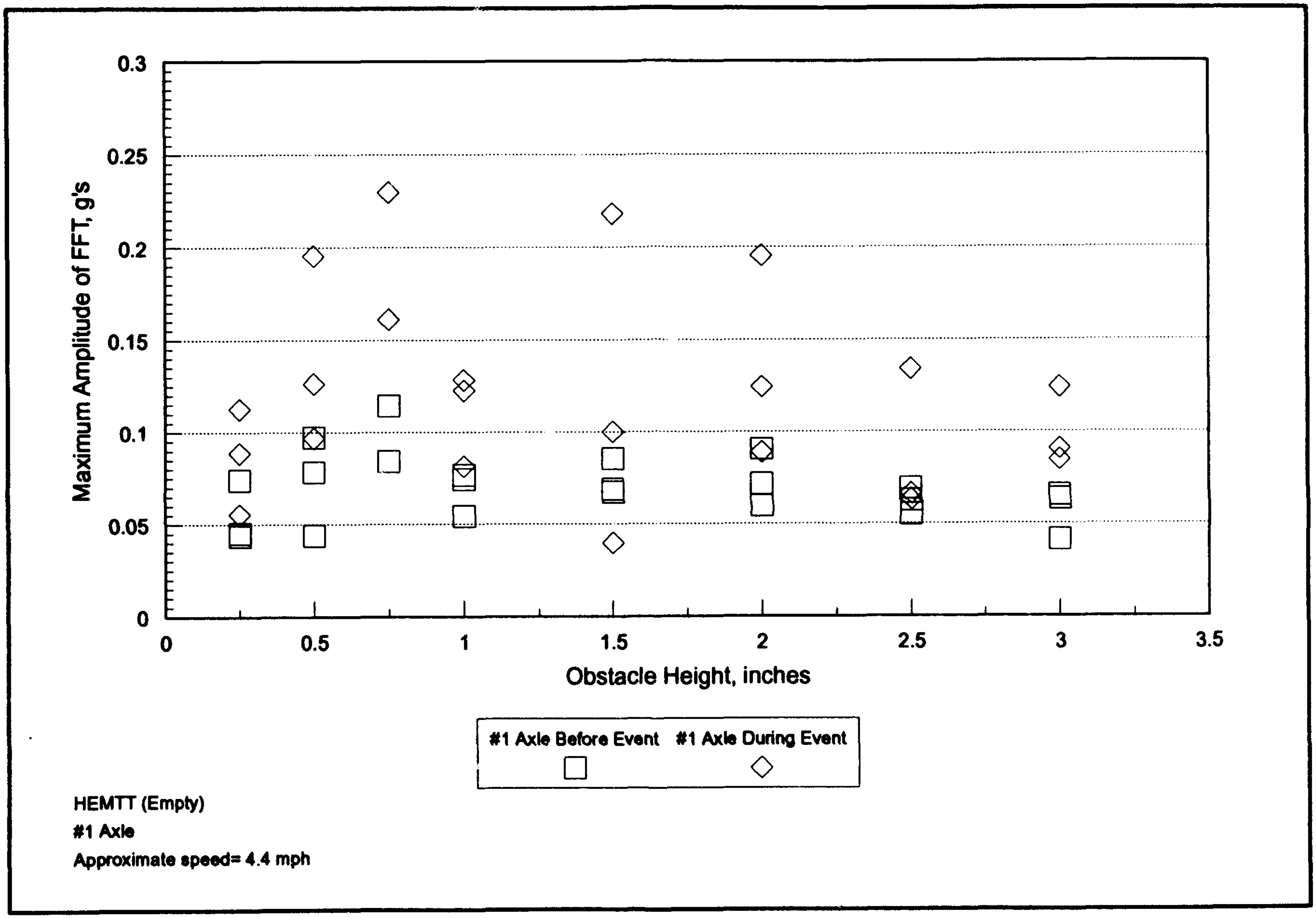

Chart C-17. Maximum amplitude of FFT versus obstacle height for axle #1 at 4.4 mph (empty vehicle).

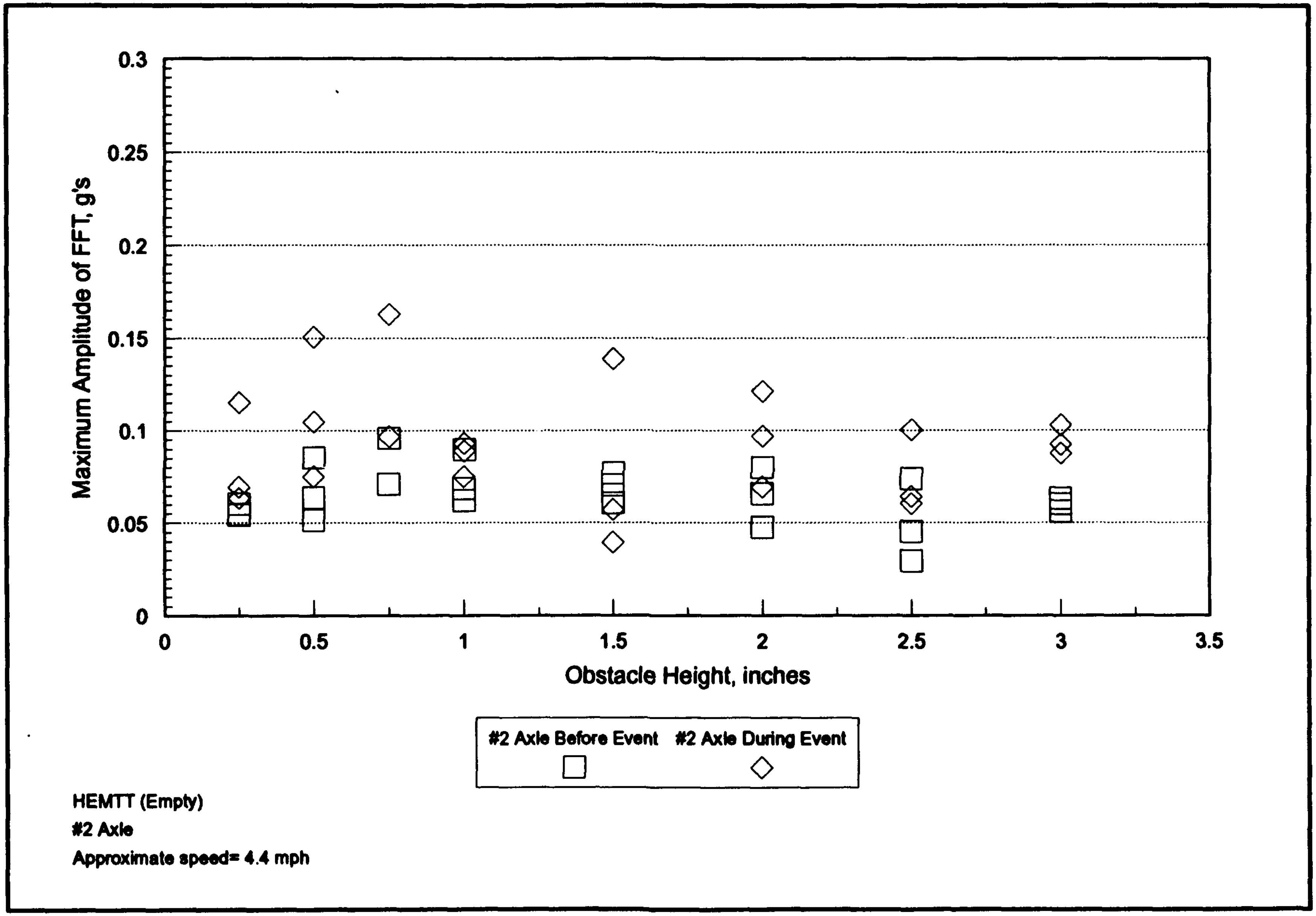

Chart C-18. Maximum amplitude of FFT versus obstacle height for axle #2 at 4.4 mph (empty vehicle).

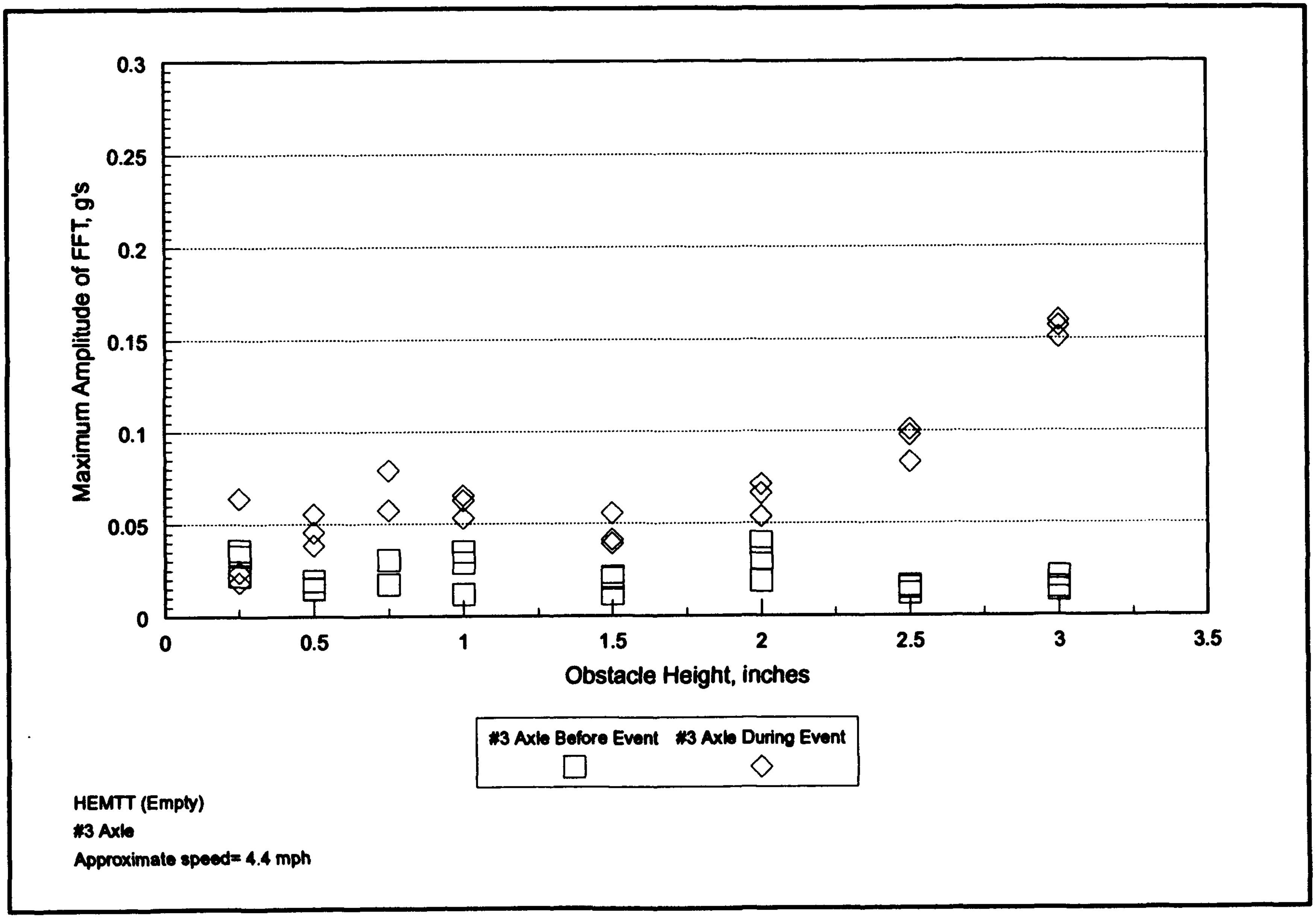

Chart C-19. Maximum amplitude of FFT versus obstacle height for axle #3 at 4.4 mph (empty vehicle).

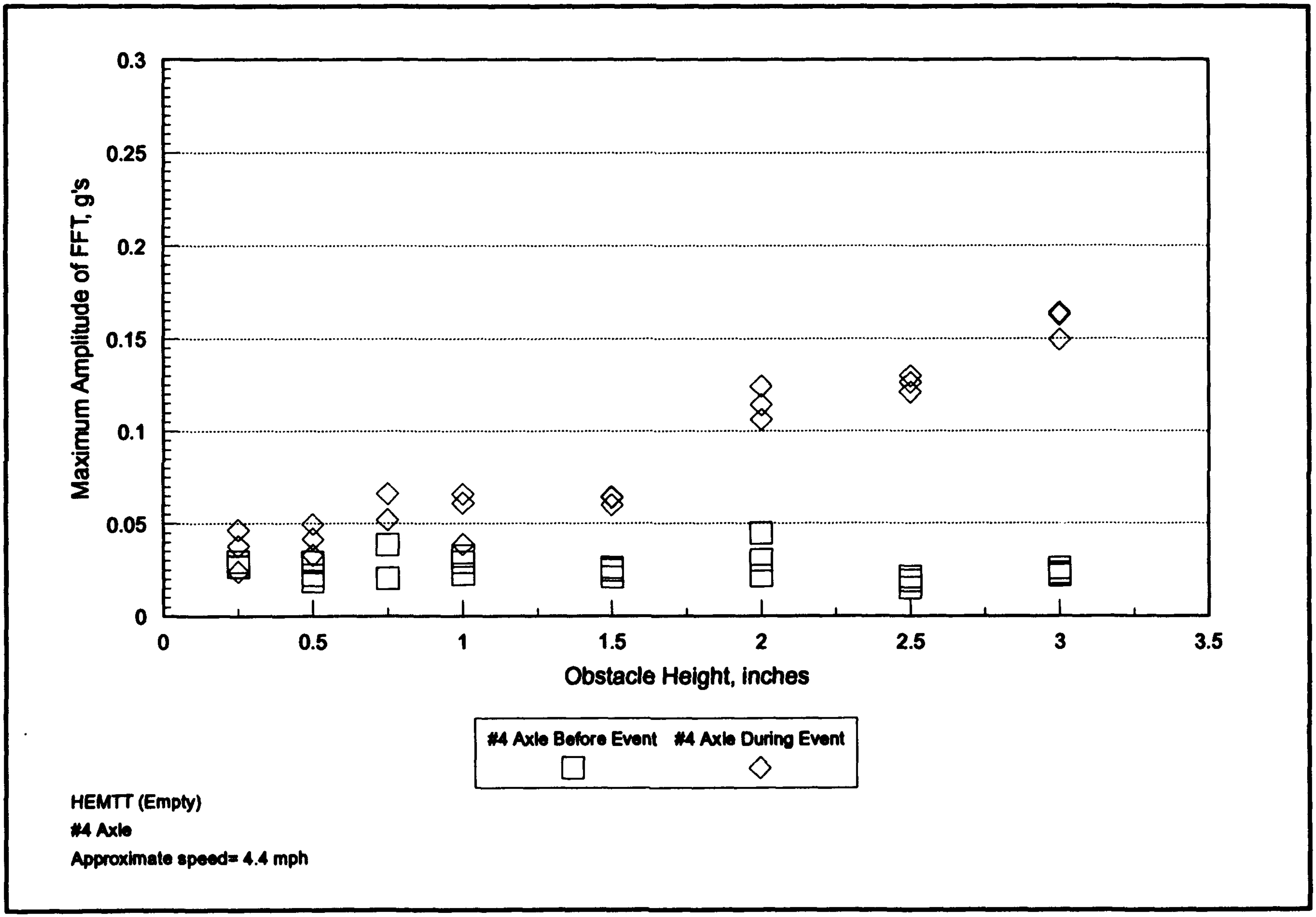

Chart C-20. Maximum amplitude of FFT versus obstacle height for axle #4 at 4.4 mph (empty vehicle).

APPENDIX D

TABULATED TEST DATA USED IN DATA PLOTS

Table D-1. Results of HEMTT dynamic tests over low profile obstacles.

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 1/4" high obstacle									
Test 43		1.78	6-15			15-17.79	21.88-24.53		
[1]Pitch, deg/sec			-0.1918			-0.1969	0.1803		
[2]Roll, deg/sec			-0.1853			0.2101	-0.2246		
[3]c.g., g's			-0.0356	2.3125	0.0081	-0.0283	-0.0231	2.3125	0.0087
[4]#1 axle, g's	15.54		-0.1376	6.1250	0.0443	0.1572		6.1875	0.0559
[4]#2 axle, g's	17.45		-0.1207	6.1250	0.0249	0.1128		6.1875	0.0289
[4]#3 axle, g's	22.28		-0.1753	6.1250	0.0585		-0.1478	6.1875	0.0831
[4]#4 axle, g's	24.19		0.2128	6.1250	0.0495		0.2021	6.1875	0.0921
Test 44		1.80	5.5-14.5			14.5-17.18	21-23.80		
Pitch, deg/sec			-0.1313			-0.1945	-0.1419		
Roll, deg/sec			-0.3045			0.3336	-0.2808		
c.g., g's			-0.0303	2.3125	0.0099	-0.0338	0.0368	2.375	0.0063
#1 axle, g's	14.94		0.1430	6.1875	0.0313	0.1587		6.3125	0.0215
#2 axle, g's	16.8		0.1186	12.4375	0.0318	0.2111		6.3125	0.0341
#3 axle, g's	21.55		0.2266	6.2500	0.0837		-0.1554	6.3750	0.0570
#4 axle, g's	23.43		0.2212	6.2500	0.0857		-0.1948	6.3750	0.0623
Test 45		1.81	4.71-14.0			14-16.68	20.6-23.29		
Pitch, deg/sec			-0.1224			-0.1731	0.1819		
Roll, deg/sec			0.2674			-0.3511	-0.2809		
c.g., g's			0.0270	2.3750	0.0053	0.0335	-0.0268	2.3750	0.0101
#1 axle, g's	14.44		0.0929	12.5000	0.0164	0.1225		6.3750	0.0208
#2 axle, g's	16.3		0.0956	6.2500	0.0199	-0.1088		2.3750	0.0151
#3 axle, g's	21.04		0.1429	6.2500	0.0593		0.3057	6.2500	0.0855
#4 axle, g's	22.91		-0.1899	6.2500	0.0695		0.3021	6.2500	0.0931
(Continued)									

[1]Vehicle pitch rate.
[2]Vehicle roll rate.
[3]Vertical acceleration of vehicle's center of gravity.
[4]Vertical acceleration of the vehicle's axles on the left side .

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 1/4" high obstacle (Concluded)									
Test 46		4.38	9.9-13.9			13.9-15.08	16.75-17.88		
Pitch, deg/sec			-0.1638			-0.2012	0.1975		
Roll, deg/sec			-0.2917			-0.2148	0.3862		
c.g., g's			-0.0471	13.5000	0.0098	0.0513	0.0364	2.2500	0.0142
#1 axle, g's	14.10		-0.3293	13.5000	0.0728	-0.3862		14.5000	0.0725
#2 axle, g's	14.93		-0.3014	13.5000	0.0741	-0.3373		15.0000	0.0846
#3 axle, g's	16.95		-0.1395	13.5000	0.0405		-0.4826	15.0000	0.1130
#4 axle, g's	17.73		-0.2033	12.7500	0.0520		0.4154	14.7500	0.0815
Test 47		4.35	10.1-14.05			14.05-15.23	16.87-18.0		
Pitch, deg/sec			-0.1442			-0.2214	0.2876		
Roll, deg/sec			0.2506			-0.2488	-0.2618		
c.g., g's			-0.0454	13.7500	0.0096	0.0576	0.0529	14.5000	0.0170
#1 axle, g's	14.25		0.2628	13.5000	0.0591	0.3951		14.5000	0.0741
#2 axle, g's	15.07		-0.2528	13.7500	0.0443	0.3021		14.5000	0.0620
#3 axle, g's	17.07		-0.1756	13.0000	0.0381		-0.3210	15.0000	0.0512
#4 axle, g's	17.84		-0.1848	13.5000	0.0368		-0.2948	7.5000	0.0482
Test 48		4.33	9.88-13.8			13.8-14.95	16.6-17.71		
Pitch, deg/sec			-0.1366	13.7500	0.0153	0.2294	0.2852		
Roll, deg/sec			0.3070	13.7500	0.0952	-0.2040	0.3665		
c.g., g's			0.0618	12.7500	0.0388	0.0651	-0.0524	2.2500	0.0469
#1 axle, g's	13.99		-0.3439	13.0000	0.0361	-0.4962		14.7500	0.0950
#2 axle, g's	14.80		0.1931	13.7500	0.0955	-0.3152		15.2500	0.0572
#3 axle, g's	16.80		-0.3288				-0.3760	15.0000	0.0776
#4 axle, g's	17.56		-0.3613				0.2714	14.7500	0.1284
HEMTT loded (60,106 lb), 1/2" high obstacle									
Test 49		1.79	4.67-14.2			14.2-16.94	21.0-23.72		
Pitch, deg/sec			0.1135			0.2060	0.2843		
Roll, deg/sec			-0.2131			-0.2602	0.3166		
c.g., g's			0.0276	2.4375	0.0040	-0.0312	-0.0659	2.4375	0.0103
#1 axle, g's	14.67		0.1626	6.0625	0.0663	-0.2157		6.1250	0.0512
#2 axle, g's	16.56		-0.1705	6.0625	0.0612	-0.2273		6.1250	0.0554
#3 axle, g's	21.41		0.1618	6.0625	0.0495		-0.2144	6.1875	0.0606
#4 axle, g's	23.34		0.1286	6.0000	0.0472		0.2105	6.1875	0.0586
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT loded (60,106 lb), 1/2" high obstacle (Continued)									
Test 50		1.80	5.12-14.4			14.4-17.02	21.0-23.68		
Pitch, deg/sec			0.1253			-0.1660	0.2819		
Roll, deg/sec			-0.2925			-0.2454	-0.3048		
c.g., g's			0.0241	2.3125	0.0072	0.0357	-0.0482	2.375	0.0099
#1 axle, g's	14.80		0.1491	6.2500	0.0648	0.1586		6.3125	0.0405
#2 axle, g's	16.65		0.1749	6.2500	0.0877	-0.1846		6.3125	0.0576
#3 axle, g's	21.41		0.2045	6.2500	0.0960		0.2080	6.2500	0.0475
#4 axle, g's	23.30		0.2449	6.2500	0.1049		0.1716	6.3125	0.0630
Test 51		1.80	5.1-14.38			14.38-17.01	21.0-23.66		
Pitch, deg/sec			-0.1212			0.2571	0.2224		
Roll, deg/sec			0.2237			0.2463	0.2228		
c.g., g's			-0.0280	2.3125	0.0076	-0.0424	0.0408	2.5625	0.0091
#1 axle, g's	14.78		-0.1196	6.2500	0.0233	0.1804		6.1250	0.0176
#2 axle, g's	16.64		-0.1380	6.2500	0.0378	-0.1522		12.5000	0.0170
#3 axle, g's	21.40		0.2099	6.2500	0.1010		-0.2434	6.3125	0.1122
#4 axle, g's	23.28		0.2211	6.2500	0.1171		0.2153	6.3125	0.1118
Test 52		4.27	11.16-15.19			15.19-16.38	18.08-19.21		
Pitch, deg/sec			-0.1671			-0.3642	0.3493		
Roll, deg/sec			-0.3222			-0.2459	0.3585		
c.g., g's			0.0411	13.3750	0.0087	0.0643	-0.0495	2.1250	0.0170
#1 axle, g's	15.39		-0.2779	12.6250	0.0670	0.3965		14.6250	0.0843
#2 axle, g's	16.23		-0.2178	13.1250	0.0506	-0.2799		7.2500	0.0516
#3 axle, g's	18.28		0.3058	12.7500	0.0596		0.4251	14.6250	0.0771
#4 axle, g's	19.06		-0.2689	13.5000	0.0639		-0.5784	14.7500	0.1334
Test 53		4.37	11.27-15.21			15.21-16.38	18.02		
Pitch, deg/sec			-0.1472			-0.3368	0.3622		
Roll, deg/sec			-0.3181			-0.3219	0.3957		
c.g., g's			0.0392	2.2500	0.0104	-0.0533	-0.0752	2.2500	0.0253
#1 axle, g's	15.41		0.3454	13.7500	0.0779	0.5101		15.2500	0.1048
#2 axle, g's	16.23		-0.1976	13.7500	0.0479	0.3780		15.2500	0.0773
#3 axle, g's	18.22		0.1770	6.7500	0.0321		-0.4730	15.0000	0.0598
#4 axle, g's	18.99		0.3581	13.7500	0.1017		0.4567	15.2500	0.0851
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values: Front Axels	Time Window (sec), and Peak Values: Rear Axels	Max. Freq. Hz	Max. Ampli.
HEMTT loded (60,106 lb), 1/2" high obstacle (Concluded)									
Test 54		4.35	10.63-14.59			14.59-15.75	17.42-18.55		
Pitch, deg/sec			-0.1551			-0.3071	0.3879		
Roll, deg/sec			-0.2784			-0.2694	0.5252		
c.g., g's			0.0428	2.5000	0.0109	-0.0600	0.0574	2.2500	0.0171
#1 axle, g's	14.79		0.2982	12.7500	0.0538	-0.2849		7.5000	0.0724
#2 axle, g's	15.60		-0.2393	13.0000	0.0504	-0.2534		7.5000	0.0657
#3 axle, g's	17.62		-0.2412	12.7500	0.0588		-0.4932	15.0000	0.1308
#4 axle, g's	18.39		0.2655	13.0000	0.0737		-0.5745	15.0000	0.1302
HEMTT loaded (60,106 lb), 3/4" high obstacle									
Test 55		1.83	6.69-15.80			15.80-18.40	22.3-24.91		
Pitch, deg/sec			0.1859			-0.2503	0.3929		
Roll, deg/sec			0.3658			0.3597	-0.5884		
c.g., g's			0.0261	2.3125	0.0075	-0.0355	-0.0563	2.6250	0.0134
#1 axle, g's	16.20		-0.1696	6.4375	0.0649	0.1838		6.4375	0.0372
#2 axle, g's	18.03		-0.1788	6.4375	0.0467	-0.1425		6.4375	0.0140
#3 axle, g's	22.70		-0.1874	6.5000	0.0571		-0.2722	6.4375	0.0563
#4 axle, g's	24.54		-0.1861	6.5000	0.0598		-0.2354	6.3750	0.0666
Test 56		1.84	5.16-14.28			14.28-16.89	20.78-23.39		
Pitch, deg/sec			0.1359			0.2790	0.3183		
Roll, deg/sec			0.4141			0.3808	-0.4731		
c.g., g's			0.0240	2.3750	0.0053	0.0298	0.0529	2.6250	0.0145
#1 axle, g's	14.68		0.1893	6.4375	0.0620	0.1704		6.4375	0.0450
#2 axle, g's	16.52		0.1676	6.4375	0.0441	-0.1744		6.4375	0.0261
#3 axle, g's	21.18		-0.1549	6.4375	0.0506		0.2966	6.3750	0.0835
#4 axle, g's	23.02		0.1881	6.3125	0.0483		0.2671	6.3750	0.0852
Test 57		1.82	6.73-15.91			15.91-18.53	22.46-25.08		
Pitch, deg/sec			0.1288			-0.3527	0.3166		
Roll, deg/sec			0.3936			-0.3316	-0.5008		
c.g., g's			0.0252	2.3750	0.0074	-0.0474	0.0427	2.6250	0.0096
#1 axle, g's	16.31		0.1548	6.3125	0.0488	0.1755		6.3125	0.0328
#2 axle, g's	18.16		0.1582	6.3125	0.0437	-0.2182		6.3125	0.0276
#3 axle, g's	22.86		0.1582	6.3125	0.0443		0.1891	6.4375	0.0422
#4 axle, g's	24.71		-0.1454	3.3750	0.0348		0.2476	6.4375	0.0422

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 3/4" high obstacle (Concluded)									
Test 58		4.46	11.87-15.75			15.75-16.91	18.53-19.63		
Pitch, deg/sec			-0.1321			-0.4573	0.5457		
Roll, deg/sec			0.3137			0.3700	0.4180		
c.g., g's			-0.0584	13.7500	0.0143	-0.0814	-0.0783	2.2500	0.0402
#1 axle, g's	15.95		-0.3940	14.0000	0.1068	-0.6261		15.2500	0.1001
#2 axle, g's	16.76		-0.3417	14.0000	0.0972	-0.4677		15.2500	0.0943
#3 axle, g's	18.73		-0.1458	13.2500	0.0183		-0.6302	15.2500	0.1746
#4 axle, g's	19.48		-0.4030	13.5000	0.1321		0.5383	15.2500	0.0966
Test 59		4.39	12.53-16.39			16.39-17.53	19.13-20.24		
Pitch, deg/sec			-0.2058			-0.5011	0.4875		
Roll, deg/sec			-0.4844			0.5145	0.4743		
c.g., g's			-0.0706	14.0000	0.0179	0.1020	0.1118	2.2500	0.0513
#1 axle, g's	16.59		-0.3453	14.0000	0.0941	-0.5210		7.7500	0.1047
#2 axle, g's	17.38		0.3511	14.0000	0.0890	0.4643		15.5000	0.0782
#3 axle, g's	19.33		-0.3255	14.2500	0.0691		0.6466	15.2500	0.1431
#4 axle, g's	20.09		-0.2688	14.2500	0.0548		0.5547	15.0000	0.1209
Test 60		4.46	12.68-16.53			16.53-17.68	19.28-20.37		
Pitch, deg/sec			-0.1138			-0.4962	0.4448		
Roll, deg/sec			-0.2302			0.3713	-0.3812		
c.g., g's			-0.0476	13.5000	0.0148	-0.0624	-0.1176	2.2500	0.0472
#1 axle, g's	16.73		0.2123	7.0000	0.0595	0.5176		7.7500	0.0865
#2 axle, g's	17.53		0.2641	7.2500	0.0568	0.4436		7.7500	0.0756
#3 axle, g's	19.48		-0.3063	14.2500	0.0540		-0.6377	15.0000	0.1383
#4 axle, g's	20.22		0.2894	14.0000	0.0634		0.4724	6.7500	0.0715
HEMTT loaded (60,106 lb), 1" high obstacle									
Test 61		1.83	5.08-14.25			14.25-16.87	20.79-23.41		
Pitch, deg/sec			0.2354			-0.3957	0.3907		
Roll, deg/sec			-0.2922			0.3145	0.4177		
c.g., g's			0.0300	2.3750	0.0068	-0.0584	0.0756	2.3125	0.0171
#1 axle, g's	14.65		0.1053	6.3750	0.0188	0.2077		2.6875	0.0149
#2 axle, g's	16.50		0.1321	12.8125	0.2586	-0.2832		3.1875	0.0157
#3 axle, g's	21.19		0.2349	6.3750	0.1163		-0.2969	6.4375	0.0307
#4 axle, g's	23.04		0.2432	6.3750	0.1150		-0.3468	6.4375	0.0384
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT loaded (60,106 lb), 1" high obstacle (Continued)									
Test 62		1.83	5.50-14.71			14.71-17.34	21.28-23.91		
Pitch, deg/sec			0.2308			0.3152	0.4521		
Roll, deg/sec			0.2672			0.2161	spike		
c.g., g's			0.0273	2.3750	0.0054	0.0469	0.0884	2.5625	0.0171
#1 axle, g's	15.11		0.1338	6.3125	0.0389	-0.1881		6.1875	0.0270
#2 axle, g's	16.97		-0.1425	6.3125	0.0407	-0.2048		6.3750	0.0303
#3 axle, g's	21.68		-0.1787	6.3750	0.0514		0.3854	6.3125	0.0571
#4 axle, g's	23.54		0.1809	6.3750	0.0635		0.4429	6.3125	0.0671
Test 63		1.84	6.83-15.91			15.91-18.51	22.39-24.98		
Pitch, deg/sec			0.1906			-0.4732	0.4054		
Roll, deg/sec			-0.2298			0.2999	-0.3766		
c.g., g's			-0.0275	6.3750	0.0046	0.0634	0.0842	2.6250	0.0199
#1 axle, g's	16.31		0.1435	6.5000	0.0485	0.2467		6.6250	0.0318
#2 axle, g's	18.14		0.1807	6.5000	0.0457	0.2213		6.3125	0.0252
#3 axle, g's	22.79		0.2252	6.3750	0.1112		0.3325	6.4375	0.0710
#4 axle, g's	24.61		0.2192	6.3750	0.1252		-0.2805	6.4375	0.0694
Test 64		4.49	12.51-16.38			16.38-17.53	19.14-20.24		
Pitch, deg/sec			-0.2217			-0.6031	0.6139		
Roll, deg/sec			0.2749			-0.2658	0.3763		
c.g., g's			0.0630	2.2500	0.0139	0.1115	-0.1421	2.2500	0.0614
#1 axle, g's	16.58		0.2409	13.2500	0.0350	0.6083		2.2500	0.0792
#2 axle, g's	17.38		0.2585	13.2500	0.0681	0.4148		2.2500	0.0670
#3 axle, g's	19.34		-0.2592	13.5000	0.0549		-0.6408	14.7500	0.0687
#4 axle, g's	20.09		-0.3055	14.2500	0.0713		-0.7160	14.7500	0.0766
Test 65		4.51	11.31-15.16			15.16-16.30	17.90-19.00		
Pitch, deg/sec			-0.1981			-0.5353	0.5477		
Roll, deg/sec			-0.2785			0.3147	0.3695		
c.g., g's			0.0385	2.2500	0.0072	0.0802	-0.1133	2.2500	0.0483
#1 axle, g's	15.36		-0.3259	14.0000	0.0743	0.4971		7.7500	0.1454
#2 axle, g's	16.15		-0.1980	7.0000	0.0383	-0.4904		7.7500	0.1123
#3 axle, g's	18.10		-0.1972	7.0000	0.0315		-0.5404	7.0000	0.0723
#4 axle, g's	18.85		-0.3084	14.0000	0.0735		0.6451	15.5000	0.1090

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 1" high obstacle (Conclued)									
Test 66		4.42	10.37-14.24			14.24-15.39	17.00-18.10		
Pitch, deg/sec			-0.1516			-0.5884	0.7207		
Roll, deg/sec			-0.2535			-0.3212	0.6624		
c.g., g's			0.0375	2.2500	0.0085	0.0866	-0.1027	2.2500	0.0477
#1 axle, g's	14.44		0.3977	14.0000	0.0978	0.5551		7.7500	0.1211
#2 axle, g's	15.24		-0.2931	7.0000	0.0508	0.4552		7.7500	0.1070
#3 axle, g's	17.20		-0.1929	14.0000	0.0470		-0.7038	15.5000	0.0900
#4 axle, g's	17.95		-0.2477	13.2500	0.0651		0.5716	7.2500	0.0751
HEMTT loaded (60,106 lb), 1 1/2" high obstacle									
Test 67		1.84	5.87-15.15			15.15-17.89	21.70-24.42		
Pitch, deg/sec			0.1221			-0.5258	0.5184		
Roll, deg/sec			0.4015			0.3866	0.4841		
c.g., g's			0.0242	2.4375	0.0054	-0.0918	0.1275	2.3125	0.0330
#1 axle, g's	15.66		0.1112	6.3125	0.0215	-0.2612		2.3125	0.0305
#2 axle, g's	17.52		0.1396	6.3750	0.0310	-0.3833		2.3125	0.0331
#3 axle, g's	22.20		0.1786	6.3750	0.0545		0.2521	6.5000	0.0346
#4 axle, g's	24.05		0.1933	6.3750	0.0588		-0.4418	6.5000	0.0533
Test 68		1.82	4.37-13.64			13.64-16.37	20.18-22.91		
Pitch, deg/sec			0.1605			-0.4799	0.4960		
Roll, deg/sec			-0.3260			-0.2912	0.4796		
c.g., g's			0.0371	2.3750	0.0041	-0.0705	-0.0904	2.3125	0.0252
#1 axle, g's	14.14		0.1499	6.3750	0.0179	0.2050		6.5625	0.0218
#2 axle, g's	16.00		-0.1068	12.7500	0.0226	-0.2494		6.5625	0.0283
#3 axle, g's	20.68		0.1900	6.3125	0.0755		-0.4686	6.2500	0.0832
#4 axle, g's	22.54		0.2813	6.3125	0.1033		0.5452	6.6250	0.1065
Test 69		1.82	6.11-15.37			15.37-18.09	21.89-24.62		
Pitch, deg/sec			0.1295			-0.5174	0.4666		
Roll, deg/sec			0.2866			0.2964	0.5683		
c.g., g's			0.0281	2.4375	0.0050	0.0763	0.1010	2.3125	0.0262
#1 axle, g's	15.87		0.1908	6.375	0.0703	0.2510		6.2500	0.0408
#2 axle, g's	17.72		-0.1554	6.375	0.0553	0.2283		2.3125	0.0298
#3 axle, g's	22.39		0.2722	6.375	0.2510		0.3251	6.2500	0.0695
#4 axle, g's	24.25		0.3556	6.375	0.2283		-0.3653	6.2500	0.0927

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT loaded (60,106 lb), 1 1/2" high obstacle (Concluded)									
Test 70		4.36	10.53-14.52			14.52-15.76	17.29-18.50		
Pitch, deg/sec			-0.1482			-0.7018	0.7253		
Roll, deg/sec			-0.2416			0.4721	0.5078		
c.g., g's			-0.0502	14.0000	0.0090	-0.1218	-0.1745	2.2500	0.0480
#1 axle, g's	14.82		0.2188	13.2500	0.0463	-0.5876		7.5000	0.0993
#2 axle, g's	15.61		0.2621	14.0000	0.0659	-0.4844		7.5000	0.0724
#3 axle, g's	17.59		-0.1771	13.2500	0.0346		-0.8114	15.2500	0.1257
#4 axle, g's	18.35		0.2728	13.0000	0.0644		-0.7998	14.7500	0.1190
Test 71		4.35	10.05-14.08			14.08-15.35	17.89-18.01		
Pitch, deg/sec			-0.1536			-0.6989	-0.3509		
Roll, deg/sec			-0.2764			0.3143	-0.2163		
c.g., g's			-0.0475	2.3750	0.0114	-0.1148	0.0647	2.2500	0.0444
#1 axle, g's	14.38		-0.3655	13.8750	0.0798	0.6848		7.5000	0.1320
#2 axle, g's	15.20		-0.2129	6.7500	0.0352	-0.5057		7.5000	0.1095
#3 axle, g's	17.19		-0.1669	13.3750	0.0284		-0.5559	15.0000	0.0651
#4 axle, g's	17.95		-0.2104	13.7500	0.0445		-0.7546	15.000	0.1330
Test 72		4.46	10.00-13.97			13.97-15.22	16.73-17.93		
Pitch, deg/sec			-0.1291			-0.6513	0.7343		
Roll, deg/sec			-0.4096			0.5273	0.4359		
c.g., g's			-0.0353	2.2500	0.0072	-0.0980	-0.1588	2.2500	0.0435
#1 axle, g's	14.27		-0.4314	14.0000	0.1142	0.6478		7.7500	0.1544
#2 axle, g's	15.07		-0.2323	6.5000	0.0496	0.4669		7.7500	0.1188
#3 axle, g's	17.03		0.1897	14.2500	0.0316		0.8259	15.5000	0.1328
#4 axle, g's	17.78		-0.2586	13.5000	0.0786		0.8832	15.0000	0.1016
HEMTT loaded (60,106 lb), 2" high obstacle									
Test 73		1.83	4.21-13.61			13.61-23.00	20.23-23.00		
Pitch, deg/sec			0.2381			-0.4313	0.4707		
Roll, deg/sec			-0.3861			0.4256	0.3728		
c.g., g's			0.0269	2.3125	0.0068	-0.0712	0.1048	2.3750	0.0398
#1 axle, g's	14.11		0.2352	6.3750	0.0812	0.2839		6.4375	0.0544
#2 axle, g's	16.00		0.2265	6.3125	0.0731	-0.3354		6.4375	0.0498
#3 axle, g's	20.73		0.1263	6.3125	0.0416		-0.3634	6.5000	0.0758
#4 axle, g's	22.63		0.2054	6.3125	0.0641		0.3961	6.5000	0.0982

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 2" high obstacle (Continued)									
Test 74		1.84	4.80-14.17			14.17-16.99	20.68-23.53		
Pitch, deg/sec			-0.1367			-0.4623	0.4425		
Roll, deg/sec			0.2484			-0.2451	0.6313		
c.g., g's			0.0357	2.4375	0.0067	-0.0695	-0.0968	2.3125	0.0323
#1 axle, g's	14.77		0.2969	6.3750	0.0508	0.3922		2.3125	0.0296
#2 axle, g's	16.62		0.1454	6.3750	0.0459	0.2479		2.3125	0.0364
#3 axle, g's	21.28		0.2351	6.5000	0.0639		-0.2947	6.5625	0.0752
#4 axle, g's	23.16		0.2274	6.5000	0.0768		0.4290	6.5625	0.1081
Test 75		1.83	4.40-13.81			13.81-16.63	20.31-23.15		
Pitch, deg/sec			-0.1389			-0.5658	0.4676		
Roll, deg/sec			0.2387			0.2811	0.2731		
c.g., g's			-0.0289	2.3750	0.0091	0.0835	0.0899	2.3125	0.0351
#1 axle, g's	14.41		-0.1831	6.4375	0.0906	0.3103		6.6250	0.0342
#2 axle, g's	16.26		-0.1812	6.4375	0.0694	-0.3003		2.3125	0.0389
#3 axle, g's	20.91		0.1955	6.5000	0.0630		0.2991	6.8125	0.0330
#4 axle, g's	22.78		0.2529	6.5000	0.0730		0.4059	6.8125	0.0465
Test 76		4.39	10.20-14.18			14.18-15.44	16.95-18.15		
Pitch, deg/sec			-0.1495			-0.7877	-0.9464		
Roll, deg/sec			-0.2362			0.3055	0.4297		
c.g., g's			-0.0618	14.0000	0.0152	-0.1537	-0.1808	2.2500	0.0487
#1 axle, g's	14.48		0.3853	14.0000	0.1235	-0.6131		7.7500	0.1042
#2 axle, g's	15.29		-0.1724	13.2500	0.0351	0.5732		7.7500	0.0714
#3 axle, g's	17.25		-0.1860	13.0000	0.0261		-0.7516	14.7500	0.0749
#4 axle, g's	18.00		-0.2651	13.5000	0.0598		-0.8722	7.5000	0.0950
Test 77		4.45	10.96-14.95			14.95-16.20	17.72-18.93		
Pitch, deg/sec			-0.1694			-0.8463	1.3152		
Roll, deg/sec			-0.3226			0.4933	-0.5653		
c.g., g's			0.0289	2.2500	0.0068	-0.1408	-0.2074	2.2500	0.0476
#1 axle, g's	15.25		0.2232	13.2500	0.0527	0.5481		7.7500	0.0937
#2 axle, g's	16.05		-0.2863	13.5000	0.0698	0.6033		5.5000	0.0726
#3 axle, g's	18.02		0.1759	6.7500	0.0220		-0.8890	15.2500	0.1552
#4 axle, g's	18.78		0.3343	14.2500	0.0767		-0.8795	14.5000	0.1277

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampl.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT loaded (60,106 lb), 2" high obstacle (Concluded)									
Test 78		4.44	10.52-14.48			14.48-15.72	*7.23-18.43		
Pitch, deg/sec			-0.1145			-0.7990	-0.9195		
Roll, deg/sec			-0.4041			0.4529	0.6135		
c.g., g's			0.0497	14.0000	0.0106	-0.1278	-0.1893	2.2500	0.0505
#1 axle, g's	14.78		-0.3851	14.2500	0.0964	-0.6255		7.7500	0.0941
#2 axle, g's	15.57		0.2407	14.2500	0.0505	-0.7105		7.7500	0.0728
#3 axle, g's	17.53		-0.3579	14.2500	0.0878		-0.7360	15.0000	0.1294
#4 axle, g's	18.28		0.2407	13.5000	0.1572		-0.7586	14.7500	0.1029
HEMTT loaded (60,106 lb), 2 1/2" high obstacle									
Test 79		1.80	4.20-15.72			13.72-16.58	20.35-23.23		
Pitch, deg/sec			0.3690			0.6035	0.4505		
Roll, deg/sec			0.2433			0.2877	0.7682		
c.g., g's			0.0445	2.3125	0.0082	-0.0690	-0.0666	2.375	0.0213
#1 axle, g's	14.32		0.2258	6.3750	0.0727	-0.2240		6.4375	0.0275
#2 axle, g's	16.21		0.1707	6.3750	0.0264	0.2097		2.3750	0.0294
#3 axle, g's	20.95		0.1731	6.3750	0.0632		0.3089	6.7500	0.0539
#4 axle, g's	22.86		0.1958	6.3750	0.0872		0.5326	6.7500	0.0758
Test 80		1.81	4.56-14.05			14.05-16.92	20.65-23.53		
Pitch, deg/sec			0.1488			0.5281	0.4880		
Roll, deg/sec			-0.3697			0.3744	-0.5841		
c.g., g's			-0.0258	2.3125	0.0089	-0.0638	-0.1043	2.3750	0.0156
#1 axle, g's	14.65		0.1380	6.3125	0.0481	0.2775		6.7500	0.0316
#2 axle, g's	16.55		0.1826	6.3125	0.0672	0.2649		6.5000	0.0309
#3 axle, g's	21.25		-0.2178	6.3750	0.0426		-0.3332	6.3125	0.0202
#4 axle, g's	23.16		-0.2839	6.3750	0.0881		-0.3532	6.8125	0.0348
Test 81		1.82	4.62-14.03			14.03-16.88	20.58-23.43		
Pitch, deg/sec			0.1506			0.5028	0.4531		
Roll, deg/sec			-0.3125			-0.3521	0.5807		
c.g., g's			0.0458	2.3750	0.0082	-0.0732	-0.0737	6.6250	0.0133
#1 axle, g's	14.63		0.1495	6.4375	0.0235	-0.1868		6.5625	0.0187
#2 axle, g's	16.51		0.1636	6.4375	0.0545	0.2261		6.8125	0.0277
#3 axle, g's	21.18		-0.1056	6.3750	0.0238		0.3421	6.4375	0.0319
#4 axle, g's	23.06		-0.1676	12.8125	0.0270		0.4508	6.4375	0.0397

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 2 1/2" high obstacle (Concluded)									
Test 82		4.46	10.26-14.27			14.27-15.53	17.06-18.27		
Pitch, deg/sec			-0.1246			0.9973	-1.2830		
Roll, deg/sec			-0.4326			0.6939	0.6769		
c.g., g's			-0.0610	2.2500	0.0154	0.1575	-0.2102	1.5000	0.0519
#1 axle, g's	14.57		-0.3782	13.8750	0.0952	-0.6232		6.7500	0.1057
#2 axle, g's	15.38		-0.4122	14.2500	0.1081	0.9698		6.7500	0.0926
#3 axle, g's	17.36		0.2186	14.2500	0.0323		0.9180	15.2500	0.1797
#4 axle, g's	18.12		0.4353	13.1250	0.1006		1.2069	7.0000	0.1300
Test 83		4.51	14.50-18.40			18.40-19.62	21.09-22.29		
Pitch, deg/sec			-0.1619			-1.0716	-1.2547		
Roll, deg/sec			-0.6377			0.6996	0.5317		
c.g., g's			0.0534	14.2500	0.0115	-0.1683	-0.1927	1.5000	0.0633
#1 axle, g's	18.70		0.3525	14.2500	0.0780	-0.8843		7.7500	0.1289
#2 axle, g's	19.47		0.2932	15.0000	0.0700	-0.8149		7.0000	0.0850
#3 axle, g's	21.39		0.4644	14.7500	0.1941		1.0539	15.2500	0.1577
#4 axle, g's	22.14		0.4806	14.7500	0.1645		1.2069	15.2500	0.1813
Test 84		4.43	10.88-14.88			14.88-16.14	17.66-18.88		
Pitch, deg/sec			-0.1148			0.9921	-1.2471		
Roll, deg/sec			0.3101			0.6457	0.8130		
c.g., g's			-0.0666	13.5000	0.0151	-0.1546	-0.1924	1.5000	0.0500
#1 axle, g's	15.18		-0.3201	13.7500	0.0675	0.8925		6.7500	0.1177
#2 axle, g's	15.99		0.3332	14.2500	0.0830	0.9458		6.7500	0.1106
#3 axle, g's	17.96		0.2831	14.2500	0.0604		1.0478	15.2500	0.1323
#4 axle, g's	18.73		0.4958	14.2500	0.1602		1.0791	7.5000	0.1275
HEMTT loaded (60,106 lb), 3" high obstacle									
Test 85		1.80	3.16-13.08			13.08-16.35	19.71-23.00		
Pitch, deg/sec			0.1291			-0.6850	0.7531		
Roll, deg/sec			-0.2985			0.3936	0.5491		
c.g., g's			0.0356	2.3125	0.0071	-0.0793	0.0732	2.5625	0.0197
#1 axle, g's	14.08		0.1663	6.3750	0.0627	-0.2152		2.3750	0.0312
#2 axle, g's	15.98		-0.1661	6.3750	0.0706	-0.2964		2.3750	0.0255
#3 axle, g's	20.71		-0.1550	6.4375	0.0512		0.3586	2.4375	0.0322
#4 axle, g's	22.63		0.1702	6.4375	0.0828		0.5564	2.5000	0.0477

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT loaded (60,106 lb), 3" high obstacle (Continued)									
Test 86		1.81	3.63-13.58			13.58-16.87	20.21-23.53		
Pitch, deg/sec			-0.2143			0.6981	0.6290		
Roll, deg/sec			-0.2738			0.3052	-0.4994		
c.g., g's			-0.0323	2.4375	0.0064	-0.0830	0.0888	2.4375	0.0294
#1 axle, g's	14.58		-0.1771	6.3125	0.0657	0.3251		2.2500	0.0225
#2 axle, g's	16.50		-0.1598	6.3125	0.0414	0.2960		2.2500	0.0298
#3 axle, g's	21.21		-0.1402	6.3750	0.0360		-0.2759	6.7500	0.0412
#4 axle, g's	23.16		0.2092	6.4375	0.0350		0.4274	6.6875	0.0677
Test 87		1.80	3.83-13.78			13.78-17.06	20.42-23.73		
Pitch, deg/sec			-0.1828			-0.8002	-0.6665		
Roll, deg/sec			-0.2834			0.3173	0.3978		
c.g., g's			-0.0292	6.3125	0.0046	0.0795	-0.0803	2.4375	0.0247
#1 axle, g's	14.78		0.2106	6.3125	0.0937	0.3530		6.9375	0.0376
#2 axle, g's	16.69		-0.2134	6.3125	0.0833	0.3750		6.9375	0.0354
#3 axle, g's	21.42		0.2374	6.3125	0.0885		0.3731	6.6875	0.0535
#4 axle, g's	23.16		0.3181	6.3125	0.1224		0.6231	6.6875	0.0789
Test 88		4.37	10.54-14.80			14.80-16.27	17.63-19.06		
Pitch, deg/sec			-0.1444			1.1712	-1.5113		
Roll, deg/sec			-0.3402			0.5790	-0.5619		
c.g., g's			-0.0421	2.3750	0.0109	-0.2028	-0.2391	2.3750	0.0590
#1 axle, g's	15.30		-0.2877	14.1250	0.0773	0.7343		6.6250	0.0913
#2 axle, g's	16.12		-0.2938	13.6250	0.0525	1.0802		6.6250	0.0978
#3 axle, g's	18.13		-0.3390	14.2500	0.0694		0.9150	14.6250	0.1413
#4 axle, g's	18.91		0.3474	13.1250	0.0919		1.3284	15.1250	0.1315
Test 89		4.39	9.83-14.08			14.08-15.55	16.90-18.33		
Pitch, deg/sec			-0.1782			1.1410	-1.5179		
Roll, deg/sec			-0.3172			0.4805	-0.5701		
c.g., g's			-0.0606	2.2500	0.0122	-0.2058	-0.2086	1.3750	0.0538
#1 axle, g's	14.58		-0.3550	14.0000	0.0931	0.9228		6.6250	0.0957
#2 axle, g's	15.40		0.3549	13.2500	0.0699	1.0755		6.6250	0.1008
#3 axle, g's	17.40		0.2343	13.3750	0.0413		1.1010	7.2500	0.1028
#4 axle, g's	18.18		-0.4319	13.8750	0.1064		1.4899	14.5000	0.1411
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT loaded (60,106 lb), 3" high obstacle (Concluded)									
Test 90		4.43	9.97-14.23			14.23-15.70	17.06-18.49		
Pitch, deg/sec			-0.1171			1.2050	-1.4617		
Roll, deg/sec			-0.3661			0.6091	-0.8442		
c.g., g's			-0.0395	2.1250	0.0073	-0.1935	0.2330	2.3750	0.0545
#1 axle, g's	14.73		0.1672	7.1250	0.0252	0.8489		6.6250	0.0953
#2 axle, g's	15.55		0.2507	12.7500	0.0495	0.9415		6.6250	0.0919
#3 axle, g's	17.56		-0.3609	12.7500	0.0467		0.8148	15.1250	0.1474
#4 axle, g's	18.34		0.3399	13.0000	0.0854		1.5288	14.8750	0.1261
HEMTT empty (38,000 lb), 1/4" high obstacle									
Test 91		1.68	3.92-14.41			14.41-17.80	21.47-24.90		
Pitch, deg/sec			-0.1371			0.1865	0.2201		
Roll, deg/sec			-0.3170			-0.2675	0.2635		
c.g., g's			0.0754	5.9375	0.0169	-0.0680	0.0697	5.8750	0.0160
#1 axle, g's	15.41		0.1296	5.8750	0.0365	0.1280		8.8125	0.0240
#2 axle, g's	17.40		0.1434	8.8125	0.0238	0.1008		8.8125	0.0204
#3 axle, g's	22.47		-0.0909	2.9375	0.0198		-0.0819	5.8125	0.0188
#4 axle, g's	24.50		0.1051	2.9375	0.0225		-0.1368	11.7500	0.0228
Test 92		1.74	4.09-14.22			14.22-17.54	21.02-24.35		
Pitch, deg/sec			-0.1540			0.1639	0.2007		
Roll, deg/sec			0.3439			0.2375	-0.3509		
c.g., g's			-0.0602	6.0000	0.0137	-0.0665	-0.0795	6.1250	0.0120
#1 axle, g's	15.22		-0.0730	6.0625	0.0176	0.1062		6.1250	0.0382
#2 axle, g's	17.15		0.1607	6.0625	0.0671	0.1244		6.0625	0.0203
#3 axle, g's	22.02		-0.1314	6.0625	0.0298		-0.1460	6.1250	0.0470
#4 axle, g's	23.96		-0.1456	6.0625	0.0313		0.1458	6.1250	0.0575
Test 93		1.77	4.16-14.17			14.17-17.45	20.88-24.18		
Pitch, deg/sec			-0.1403			-0.1554	0.1331		
Roll, deg/sec			-0.3556			0.4045	-0.4015		
c.g., g's			0.0727	6.1250	0.0178	0.0747	0.0688	6.1875	0.0181
#1 axle, g's	15.17		0.2074	6.1250	0.0694	0.2181		6.1875	0.1016
#2 axle, g's	17.07		-0.1458	6.1875	0.0508	-0.1443		6.1875	0.0694
#3 axle, g's	21.88		-0.0980	12.3125	0.0172		-0.1098	6.1250	0.0253
#4 axle, g's	23.80		-0.0988	12.3125	0.0187		0.1091	12.3125	0.0200

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 1/4" high obstacle (Concluded)									
Test 94		4.44	9.35-13.47			13.47-14.90	16.19-17.59		
Pitch, deg/sec			-0.2250			-0.2356	0.2640		
Roll, deg/sec			-0.4613			0.2983	0.4239		
c.g., g's			-0.1240	13.5000	0.0274	-0.1257	-0.1343	15.3750	0.0252
#1 axle, g's	13.97		0.2612	6.8750	0.0438	0.2491		7.7500	0.1127
#2 axle, g's	14.75		-0.2642	13.7500	0.0547	-0.2588		7.7500	0.1151
#3 axle, g's	16.69		-0.1473	13.5000	0.0330		0.2152	15.1250	0.0184
#4 axle, g's	17.44		0.1532	13.6250	0.0294		0.1608	15.3750	0.0240
Test 95		4.50	9.11-13.17			13.17-14.59	15.84-17.23		
Pitch, deg/sec			-0.1954			0.2709	0.2979		
Roll, deg/sec			0.6158			0.3375	0.4247		
c.g., g's			0.1811	13.2500	0.0430	0.1191	-0.1402	15.7500	0.0284
#1 axle, g's	13.67		0.3736	14.2500	0.0742	-0.3451		15.7500	0.0888
#2 axle, g's	14.44		-0.3066	14.6250	0.0545	-0.2953		7.8750	0.0694
#3 axle, g's	16.34		0.1749	13.6250	0.0359		0.2541	2.6250	0.0241
#4 axle, g's	17.08		-0.1853	14.3750	0.0266		0.2221	15.6250	0.0379
Test 96		4.54	9.51-13.54			13.54-14.95	16.19-17.57		
Pitch, deg/sec			-0.2500			-0.2297	0.3595		
Roll, deg/sec			-0.5034			0.3836	-0.4617		
c.g., g's			-0.1355	13.5000	0.0300	-0.1037	0.1743	15.8750	0.0510
#1 axle, g's	14.04		0.3171	7.1250	0.0453	-0.2582		15.7500	0.0555
#2 axle, g's	14.80		-0.2862	13.8750	0.0605	-0.2388		15.8750	0.0634
#3 axle, g's	16.69		-0.1262	14.7500	0.0223		-0.3142	15.6250	0.0641
#4 axle, g's	17.42		-0.1349	13.6250	0.0268		0.2152	15.8750	0.0466
HEMTT empty (38,000 lb), 1/2" obstacle									
Test 97		1.76	4.10-14.13			14.13-17.42	20.85-24.16		
Pitch, deg/sec			-0.1474			0.2559	0.1994		
Roll, deg/sec			0.3176			0.3600	0.4749		
c.g., g's			0.0714	3.0000	0.0126	-0.0758	0.0727	3.1250	0.0163
#1 axle, g's	15.13		0.1503	6.1875	0.0371	0.1388		6.1250	0.0406
#2 axle, g's	17.04		0.1866	6.1875	0.0763	0.2238		6.1250	0.0944
#3 axle, g's	21.85		0.1003	6.1250	0.0143		0.0973	3.1250	0.0172
#4 axle, g's	23.78		-0.0833	12.3125	0.0177		0.1533	6.1250	0.0201

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT empty (38,000 lb), 1/2" obstacle (Continued)									
Test 98		1.83	3.48-13.39			13.39-16.64	20.02-23.30		
Pitch, deg/sec			-0.1262			-0.2144	0.1817		
Roll, deg/sec			0.2714			0.5285	0.7470		
c.g., g's			0.0427	3.1250	0.0091	0.0730	-0.0668	3.1250	0.0108
#1 axle, g's	14.39		-0.0848	6.1250	0.0164	0.1304		12.3750	0.0146
#2 axle, g's	16.27		0.1329	6.3125	0.0419	-0.1829		6.2500	0.0522
#3 axle, g's	21.02		-0.0849	6.3125	0.0283		0.1479	6.1875	0.0210
#4 axle, g's	22.93		0.0953	6.3125	0.0229		-0.1567	12.5000	0.0272
Test 99		1.82	3.94-13.73			13.73-16.95	20.27-23.52		
Pitch, deg/sec			-0.0957			-0.2115	-0.2150		
Roll, deg/sec			-0.4841			0.2851	-0.6107		
c.g., g's			-0.0601	6.3125	0.0117	0.0554	0.0567	2.9375	0.0092
#1 axle, g's	14.73		0.0886	6.2500	0.0214	0.1474		6.3125	0.0861
#2 axle, g's	16.58		0.0935	6.1875	0.0175	0.1431		6.3125	0.0949
#3 axle, g's	21.27		-0.0623	12.6875	0.0094		0.1423	6.2500	0.0176
#4 axle, g's	23.15		-0.0851	6.3125	0.0130		-0.1483	12.5625	0.0205
Test 100		4.52	9.09-13.14			13.14-14.56	15.80-17.19		
Pitch, deg/sec			-0.2234			-0.3793	0.4025		
Roll, deg/sec			0.6020			-0.2827	0.7301		
c.g., g's			0.1649	14.3750	0.0359	0.1271	0.1668	15.5000	0.0382
#1 axle, g's	13.64		-0.2491	7.2500	0.0441	0.3977		7.7500	0.0969
#2 axle, g's	14.41		0.2781	13.6250	0.0639	0.2776		7.7500	0.0751
#3 axle, g's	16.30		-0.0914	13.5000	0.0194		0.3273	15.5000	0.0457
#4 axle, g's	17.04		-0.1278	7.2500	0.0189		0.4272	15.5000	0.0496
Test 101		4.54	8.95-12.99			12.99-14.40	15.64-17.03		
Pitch, deg/sec			-0.1862			-0.3681	0.3278		
Roll, deg/sec			-0.3958			0.2720	-0.8310		
c.g., g's			0.1142	14.2500	0.0237	-0.1158	-0.1532	15.6250	0.0237
#1 axle, g's	13.49		-0.2640	7.1250	0.0785	-0.3773		7.7500	0.1264
#2 axle, g's	14.25		0.2812	7.1250	0.0515	0.3657		7.7500	0.1048
#3 axle, g's	16.14		0.1151	14.2500	0.0152		0.4243	15.6250	0.0555
#4 axle, g's	16.88		0.1424	13.7500	0.0221		-0.3923	15.6250	0.0417
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 1/2" obstacle (Concluded)									
Test 102		4.60	8.51-12.48			12.48-13.87	15.09-16.45		
Pitch, deg/sec			0.3145			-0.5252	0.4170		
Roll, deg/sec			-0.3941			0.3458	0.4572		
c.g., g's			-0.1732	13.7500	0.0565	-0.0812	-0.1511	2.7500	0.0256
#1 axle, g's	12.98		-0.3733	7.2500	0.0974	0.4373		8.0000	0.1955
#2 axle, g's	13.73		-0.2658	7.2500	0.0855	-0.3109		8.0000	0.1507
#3 axle, g's	15.59		0.1095	14.7500	0.0149		0.3636	2.7500	0.0385
#4 axle, g's	16.31		-0.1258	14.7500	0.0293		-0.2979	2.7500	0.0329
HEMTT empty (38,000 lb), 3/4" obstacle									
Test 103		1.79	3.99-13.91			13.91-17.18	20.56-23.83		
Pitch, deg/sec			-0.1276			-0.4992	0.2536		
Roll, deg/sec			0.3585			-0.2742	0.4096		
c.g., g's			0.0751	6.2500	0.0126	-0.0779	-0.0823	6.2500	0.0211
#1 axle, g's	14.91		0.1758	6.2500	0.0652	0.2818		6.2500	0.0969
#2 axle, g's	16.80		-01571	6.2500	0.0475	0.2344		6.2500	0.0783
#3 axle, g's	21.56		-0.1004	2.9375	0.0163		0.1329	6.2500	0.0245
#4 axle, g's	23.45		-0.9057	6.2500	0.0220		-0.1897	6.1875	0.0205
Test 104		1.82	3.69-13.43			13.43-16.65	19.94-23.17		
Pitch, deg/sec			-0.1282			-0.3341	0.3627		
Roll, deg/sec			0.6030			-0.5224	0.3995		
c.g., g's			0.0543	12.8125	0.0089	-0.0751	-0.0792	2.8125	0.0093
#1 axle, g's	14.43		0.2117	6.3750	0.1060	-0.1922		6.3125	0.0597
#2 axle, g's	16.28		-0.1797	6.3750	0.0907	0.2111		6.3125	0.0821
#3 axle, g's	20.94		0.1243	6.3750	0.0325		-0.1713	6.3125	0.0495
#4 axle, g's	22.80		0.1268	6.3750	0.0302		0.1665	6.3125	0.0461
Test 105		1.83	3.36-13.08			13.08-16.29	19.57-22.80		
Pitch, deg/sec			-0.1015			-0.3666	0.2264		
Roll, deg/sec			-0.7445			-0.5121	0.6772		
c.g., g's			0.0569	12.7500	0.0143	0.0666	-0.0760	3.0625	0.0111
#1 axle, g's	14.08		0.1558	6.3750	0.0475	0.1735		6.4375	0.0384
#2 axle, g's	15.92		0.1459	6.4375	0.0464	-0.1835		6.3750	0.0302
#3 axle, g's	20.57		-0.1036	6.3125	0.0344		0.1677	6.3750	0.0493
#4 axle, g's	22.43		-0.1267	6.3125	0.0337		-0.2074	6.3750	0.0645

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 3/4" obstacle (Concluded)									
Test 106		4.60	8.82-12.79			12.79-14.18	15.39-16.76		
Pitch, deg/sec			0.2085			-0.5745	-0.3938		
Roll, deg/sec			-0.6547			-0.5508	0.7821		
c.g., g's			-0.1052	4.7500	0.0267	-0.1206	0.2419	16.0000	0.0406
#1 axle, g's	13.29		0.3283	14.7500	0.0844	0.4851		8.0000	0.1612
#2 axle, g's	14.04		-0.3788	14.0000	0.0959	-0.3268		8.0000	0.0967
#3 axle, g's	15.89		0.1659	14.7500	0.0305		0.3662	15.7500	0.0575
#4 axle, g's	16.62		0.1231	14.2500	0.0204		0.4085	16.0000	0.0520
Test 107		4.62	9.94-13.51			13.51-14.50	15.71-17.08		
Pitch, deg/sec			-0.2381			-0.5676	0.5103		
Roll, deg/sec			0.3686			0.4048	0.4803		
c.g., g's			-0.1115	5.0000	0.0335	-0.1035	-0.1589	2.5000	0.0326
#1 axle, g's	13.61		0.3082	7.5000	0.1144	0.4963		8.0000	0.2298
#2 axle, g's	14.36		0.2657	7.5000	0.0711	-0.4335		8.0000	0.1629
#3 axle, g's	16.21		0.1063	2.7500	0.0173		0.4048	16.0000	0.0792
#4 axle, g's	16.94		0.1617	15.2500	0.0386		-0.4302	16.0000	0.0662
Test 108	Analog data corrupted								
Pitch, deg/sec									
Roll, deg/sec									
c.g., g's									
#1 axle, g's									
#2 axle, g's									
#3 axle, g's									
#4 axle, g's									
HEMTT empty (38,000 lb), 1" obstacle									
Test 109		1.88	2.93-12.70			12.70-15.92	19.24-22.47		
Pitch, deg/sec			-0.1283			-0.4684	0.3401		
Roll, deg/sec			-0.4166			0.2486	0.3986		
c.g., g's			-0.0576	6.3750	0.0151	0.0882	-0.1236	3.1875	0.0149
#1 axle, g's	13.70		0.1099	3.1875	0.0191	0.2406		6.3125	0.0255
#2 axle, g's	15.56		0.1425	6.3125	0.0693	0.1974		6.3125	0.0246
#3 axle, g's	20.24		-0.1152	6.3750	0.0364		0.1977	6.3750	0.0456
#4 axle, g's	22.11		0.1171	6.3750	0.0309		0.2227	6.3750	0.0431

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT empty (38,000 lb), 1" obstacle (Continued)									
Test 110		1.92	2.97-12.68			12.68-15.88	19.18-22.39		
Pitch, deg/sec			-0.1135			-0.4871	0.2851		
Roll, deg/sec			0.4578			-0.2967	0.6624		
c.g., g's			-0.0573	6.3750	0.0191	0.0802	-0.0617	3.1875	0.0132
#1 axle, g's	13.68		0.1492	6.3750	0.0668	0.2229		6.4375	0.0626
#2 axle, g's	15.53		-0.1387	3.1875	0.0251	-0.2629		6.3750	0.0368
#3 axle, g's	20.18		-0.0576	6.3125	0.0231		0.1661	6.3750	0.0204
#4 axle, g's	22.04		0.0738	6.3125	0.0213		0.2083	6.3750	0.0246
Test 111		1.81	2.72-12.52			12.52-15.76	19.08-22.32		
Pitch, deg/sec			-0.1009			-0.4128	0.3332		
Roll, deg/sec			0.5639			-0.5930	-0.5885		
c.g., g's			0.0559	6.3750	0.0170	-0.0740	-0.0869	6.2500	0.0108
#1 axle, g's	13.52		0.1412	6.3750	0.0838	0.2204		6.3125	0.0657
#2 axle, g's	15.39		0.2090	6.3750	0.1009	0.2411		6.3125	0.0661
#3 axle, g's	20.08		0.1337	6.3125	0.0635		-0.4806	6.3125	0.0523
#4 axle, g's	21.95		0.1504	6.3125	0.0642		-0.2282	6.3125	0.0662
Test 112		4.64	8.70-12.64			12.64-14.02	15.22-16.58		
Pitch, deg/sec			0.1997			-0.6962	0.6159		
Roll, deg/sec			-0.5003			-0.3646	-0.7421		
c.g., g's			-0.0942	4.7500	0.0239	-0.0967	0.2009	2.5000	0.0300
#1 axle, g's	13.14		0.3427	15.0000	0.0744	0.3918		16.2500	0.0815
#2 axle, g's	13.88		-0.3646	14.2500	0.0898	-0.3973		16.2500	0.0931
#3 axle, g's	15.72		0.1056	14.5000	0.0118		0.4512	16.0000	0.0531
#4 axle, g's	16.44		-0.1347	14.5000	0.0228		-0.3816	16.0000	0.0388
Test 113		4.71	8.73-12.67			12.67-14.05	15.25-16.61		
Pitch, deg/sec			-0.2583			-0.6981	-0.4963		
Roll, deg/sec			-0.4940			-0.5029	-0.7418		
c.g., g's			0.1776	14.0000	0.0491	0.1982	-0.1799	15.7500	0.0336
#1 axle, g's	13.17		0.3407	14.0000	0.0768	-0.3074		8.0000	0.1226
#2 axle, g's	13.91		-0.3212	14.2500	0.0688	0.3285		8.0000	0.0752
#3 axle, g's	15.75		-0.1841	15.0000	0.0289		0.5287	15.7500	0.0628
#4 axle, g's	16.47		-0.2329	15.2500	0.0291		0.4305	15.7500	0.0611

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT empty (38,000 lb), 1" obstacle (Concluded)									
Test 114		4.61	8.51-12.48			12.48-13.87	15.09-16.45		
Pitch, deg/sec			0.2745			-0.7489	0.5904		
Roll, deg/sec			-0.4356			-0.5355	-0.6696		
c.g., g's			-0.1214	14.0000	0.0291	0.1722	-0.3031	16.0000	0.0608
#1 axle, g's	12.98		-0.2145	7.5000	0.0545	-0.3070		8.0000	0.1283
#2 axle, g's	13.73		0.2956	15.0000	0.0623	0.3061		16.2500	0.0891
#3 axle, g's	15.59		-0.1738	15.0000	0.0349		-0.4425	15.7500	0.0655
#4 axle, g's	16.31		-0.1899	15.0000	0.0327		-0.4000	3.0000	0.0660
HEMTT empty (38,000 lb), 1 1/2" obstacle									
Test 115		1.78	4.48-14.42			14.42-17.69	21.07-24.36		
Pitch, deg/sec			-0.1588			-0.4369	0.4463		
Roll, deg/sec			-0.3679			0.2547	0.2972		
c.g., g's			0.0653	6.2500	0.0254	0.1241	-0.0914	4.8750	0.0161
#1 axle, g's	15.42		0.1889	6.2500	0.0598	0.2844		6.2500	0.0261
#2 axle, g's	17.31		0.1702	6.3125	0.0650	0.2320		6.2500	0.0414
#3 axle, g's	22.07		0.1412	6.3125	0.0333		0.2679	6.1875	0.0494
#4 axle, g's	23.98		0.1436	6.3125	0.0407		0.2973	6.1875	0.0493
Test 116		1.83	3.55-13.43			13.43-16.68	20.04-23.31		
Pitch, deg/sec			-0.1294			-0.4134	0.4889		
Roll, deg/sec			0.5840			0.3668	0.3538		
c.g., g's			0.0644	6.3750	0.0141	0.1139	-0.1178	4.9375	0.0185
#1 axle, g's	14.43		-0.0922	6.3125	0.0159	0.2486		2.4375	0.0254
#2 axle, g's	16.31		0.1492	6.3125	0.0630	0.2329		6.2500	0.0223
#3 axle, g's	21.04		0.1407	6.2500	0.0378		0.2320	6.2500	0.0230
#4 axle, g's	22.94		-0.1492	6.3125	0.0526		0.2235	3.1250	0.0223
Test 117		1.81	3.27-13.20			13.20-16.47	19.85-23.13		
Pitch, deg/sec			-0.1347			-0.4510	-0.4674		
Roll, deg/sec			0.5709			-0.3782	0.4983		
c.g., g's			0.0605	6.1875	0.0123	-0.1217	0.1122	6.2500	0.0154
#1 axle, g's	14.20		0.1588	6.3125	0.0329	0.2818		6.2500	0.0360
#2 axle, g's	16.10		0.1253	6.3125	0.0187	0.3049		6.12500	0.0256
#3 axle, g's	20.85		0.1208	6.2500	0.0333		-0.2587	6.2500	0.0457
#4 axle, g's	22.76		-0.1507	6.2500	0.0468		-0.2922	6.2500	0.0593

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 1 1/2" obstacle (Concluded)									
Test 118		4.57	7.60-12.09			12.09-14.00	14.71-16.58		
Pitch, deg/sec			0.2206			-0.8695	0.7904		
Roll, deg/sec			-0.6000			-0.3750	-0.8485		
c.g., g's			0.1593	4.7500	0.0234	0.1962	-0.2497	1.5000	0.0325
#1 axle, g's	13.09		0.3049	7.1250	0.0691	0.4131		2.2500	0.0398
#2 axle, g's	13.85		-0.3252	7.1250	0.0770	-0.4119		16.2500	0.0396
#3 axle, g's	15.71		-0.1401	14.8750	0.0117		0.3879	2.8750	0.0413
#4 axle, g's	16.44		-0.1773	13.1250	0.0262		-0.5671	3.1250	0.0641
Test 119		4.60	7.56-12.03			12.03-13.92	14.64-16.50		
Pitch, deg/sec			-0.2246			-0.8551	-0.8317		
Roll, deg/sec			-0.7364			-0.3984	-1.0178		
c.g., g's			0.1077	4.8750	0.0231	0.2122	-0.2457	16.0000	0.0340
#1 axle, g's	13.03		0.3472	15.0000	0.0673	0.5798		8.0000	0.1001
#2 axle, g's	13.78		0.4247	14.2500	0.0706	-0.3535		16.0000	0.0572
#3 axle, g's	15.64		0.1228	14.6250	0.0204		-0.4279	16.0000	0.0558
#4 axle, g's	16.36		-0.14577	14.6250	0.0210		-0.6187	3.2500	0.0601
Test 120		4.69	7.44-11.89			11.89-13.78	14.48-16.34		
Pitch, deg/sec			-0.2365			-0.8214	-0.7677		
Roll, deg/sec			-0.5480			-0.4496	-0.7301		
c.g., g's			0.1801	14.1250	0.0418	0.2451	-0.2062	1.5000	0.0316
#1 axle, g's	12.89		0.3609	14.1250	0.0857	0.5678		8.0000	0.2182
#2 axle, g's	13.64		0.3040	14.1250	0.0608	-0.5264		8.0000	0.1388
#3 axle, g's	15.48		-0.1344	13.5000	0.0212		-0.4057	2.8750	0.0393
#4 axle, g's	16.20		0.1954	7.2500	0.0247		-0.4956	3.2500	0.0645
HEMTT empty (38,000 lb), 2" obstacle									
Test 121		1.80	6.51-16.38			16.38-19.65	22.98-26.25		
Pitch, deg/sec			-0.1052			-0.6312	0.5196		
Roll, deg/sec			-0.5207			0.6683	0.6084		
c.g., g's			0.0576	6.3750	0.0115	-0.0999	-0.0949	4.9375	0.0194
#1 axle, g's	17.38		0.1163	9.5000	0.0247	0.2634		6.3125	0.0222
#2 axle, g's	19.28		0.1351	6.3125	0.0249	-0.2037		6.1250	0.0241
#3 axle, g's	23.98		0.915	6.3125	0.0267		-0.2205	2.9375	0.0204
#4 axle, g's	25.88		-0.1268	6.3125	0.0374		-0.2225	2.9375	0.0244

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 2" obstacle (Continued)									
Test 122		1.84	3.35-13.13			13.13-16.39	19.65-22.91		
Pitch, deg/sec			-0.1455			-0.5222	0.5265		
Roll, deg/sec			0.5086			-0.4837	-0.6466		
c.g., g's			-0.0795	6.4375	0.0121	0.1201	-0.1139	5.0000	0.0192
#1 axle, g's	14.13		0.1923	6.3750	0.0630	0.2999		6.2500	0.0410
#2 axle, g's	16.02		-0.1572	6.3750	0.0525	0.3070		6.6250	0.0216
#3 axle, g's	20.65		0.1019	2.9375	0.0116		0.2820	6.5000	0.0172
#4 axle, g's	22.54		-0.0956	2.9375	0.0139		0.3673	4.9375	0.0181
Test 123		1.80	3.72-13.57			13.57-16.83	20.16-23.42		
Pitch, deg/sec			-0.1490			-0.6088	0.5833		
Roll, deg/sec			-0.6590			0.6259	0.6011		
c.g., g's			-0.0634	6.3125	0.0164	0.1085	0.1025	4.9375	0.0139
#1 axle, g's	14.57		0.1593	6.3125	0.0515	0.2232		6.4375	0.0264
#2 axle, g's	16.46		-0.1302	3.1875	0.0280	0.2227		6.5000	0.0233
#3 axle, g's	21.16		-0.0918	3.0000	0.0094		0.2146	4.9375	0.0180
#4 axle, g's	23.05		0.0866	12.5625	0.0217		0.2447	4.8750	0.0167
Test 124		4.58	8.50-12.51			12.51-13.91	15.14-16.52		
Pitch, deg/sec			0.2286			1.1533	-1.3071		
Roll, deg/sec			-0.4480			0.4053	1.0436		
c.g., g's			0.2138	13.8750	0.0437	0.2576	0.3247	1.5000	0.0501
#1 axle, g's	13.01		0.2834	15.2500	0.0598	0.6301		8.0000	0.0890
#2 axle, g's	13.77		0.2330	15.2500	0.0476	-0.5520		16.2500	0.0694
#3 axle, g's	15.64		0.1240	7.1250	0.0188		-0.6553	2.6250	0.0665
#4 axle, g's	16.38		-0.1731	7.1250	0.0217		-0.9029	3.1250	0.1143
Test 125		4.67	8.87-12.85			12.85-14.24	15.45-16.83		
Pitch, deg/sec			-0.3358			1.1067	-1.3545		
Roll, deg/sec			-0.5393			0.8911	0.9304		
c.g., g's			-0.1662	14.0000	0.0400	0.3180	0.2930	1.5000	0.0525
#1 axle, g's	13.35		0.3882	14.2500	0.0907	-0.6445		8.0000	0.1955
#2 axle, g's	14.10		-0.2829	14.2500	0.0658	-0.6251		8.0000	0.1213
#3 axle, g's	15.95		-0.2412	15.2500	0.0397		-0.6160	2.7500	0.0714
#4 axle, g's	16.69		-0.2616	15.2500	0.0449		-0.8526	3.0000	0.1063

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 2" obstacle (Concluded)									
Test 126		4.45	9.23-13.34			13.34-14.78	16.05-17.45		
Pitch, deg/sec			-0.2351			1.0842	-1.3007		
Roll, deg/sec			-0.6049			-0.4809	-1.0783		
c.g., g's			0.1096	13.5000	0.0240	0.3205	-0.2824	3.0000	0.0521
#1 axle, g's	13.84		0.3189	13.7500	0.0717	-0.5770		7.7500	0.1245
#2 axle, g's	14.63		0.3492	13.7500	0.0800	-0.6048		7.7500	0.0970
#3 axle, g's	16.55		-0.1412	13.7500	0.0307		0.5084	1.3750	0.0539
#4 axle, g's	17.30		-0.1638	14.6250	0.0303		-0.8867	3.0000	0.1243
HEMTT empty (38,000 lb), 2 1/2" obstacle									
Test 127		1.78	3.30-13.30			13.30-16.61	19.98-23.30		
Pitch, deg/sec			0.1107			-0.7469	0.6977		
Roll, deg/sec			0.6437			0.5558	-0.6230		
c.g., g's			-0.0723	2.3750	0.0095	0.1623	-0.1018	3.1250	0.0151
#1 axle, g's	14.30		0.1579	6.3750	0.0288	0.2983		6.3750	0.0398
#2 axle, g's	16.23		-0.1160	6.3750	0.0337	0.2498		6.0625	0.0255
#3 axle, g's	20.98		-0.1280	6.2500	0.0480		0.2844	6.3125	0.0220
#4 axle, g's	22.92		0.1398	6.2500	0.0473		0.4375	6.3750	0.0259
Test 128		1.82	2.01-11.81			11.81-15.07	18.35-21.61		
Pitch, deg/sec			-0.1196			-0.8926	0.6908		
Roll, deg/sec			0.4864			0.4456	-0.5081		
c.g., g's			-0.0451	12.8750	0.0081	0.1573	-0.1145	5.0000	0.0285
#1 axle, g's	12.81		0.2282	6.4375	0.0878	-0.2625		6.1875	0.0455
#2 axle, g's	14.70		-0.1609	6.4375	0.0346	0.2383		6.5000	0.0452
#3 axle, g's	19.35		-0.1133	6.3750	0.0400		-0.2867	6.1875	0.0269
#4 axle, g's	21.24		-0.1159	6.3750	0.0540		0.3146	6.6250	0.0322
Test 129		1.88	2.19-11.96			11.96-15.21	18.48-21.73		
Pitch, deg/sec			-0.1242			-0.8281	-0.7032		
Roll, deg/sec			-0.4452			0.5432	0.5649		
c.g., g's			0.0383	6.5000	0.0080	0.1337	-0.0913	5.0000	0.0173
#1 axle, g's	12.96		0.1393	6.4375	0.0647	0.3245		6.5625	0.0206
#2 axle, g's	14.85		-0.1957	6.4375	0.0773	0.2916		6.5625	0.0515
#3 axle, g's	19.48		-0.1199	6.4375	0.0361		-0.3324	6.4375	0.0244
#4 axle, g's	21.37		0.1083	6.4375	0.0414		0.3392	6.4375	0.0256

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 2 1/2" obstacle (Concluded)									
Test 130		4.51	9.63-14.19			14.19-16.11	16.85-18.75		
Pitch, deg/sec			-0.2665			1.4100	-1.7833		
Roll, deg/sec			-0.4581			0.7801	1.5356		
c.g., g's			0.1098	4.7500	0.0262	0.3272	0.3164	2.6250	0.0500
#1 axle, g's	15.19		0.3450	15.0000	0.0692	0.6845		16.0000	0.0665
#2 axle, g's	15.96		0.5810	14.8750	0.0740	0.8083		15.8750	0.0642
#3 axle, g's	17.85		0.1398	14.5000	0.0151		0.7512	2.6250	0.1009
#4 axle, g's	18.60		0.1793	3.0000	0.0190		1.1480	3.0000	0.0126
Test 131		4.51	8.85-13.41			13.41-15.33	16.07-17.97		
Pitch, deg/sec			-0.2709			1.3782	-1.6121		
Roll, deg/sec			-0.5912			0.6758	1.2236		
c.g., g's			0.1073	4.7500	0.0243	0.3479	0.3780	2.6250	0.0578
#1 axle, g's	14.41		0.3036	14.7500	0.0628	-0.7884		8.1250	0.0632
#2 axle, g's	15.18		-0.2773	14.3750	0.0453	0.7197		16.0000	0.0604
#3 axle, g's	17.07		-0.1015	15.2500	0.0120		0.8802	2.6250	0.0979
#4 axle, g's	17.82		0.1254	7.1250	0.0211		-0.9633	3.0000	0.1298
Test 132		4.59	7.39-11.89			11.89-13.79	14.52-16.39		
Pitch, deg/sec			0.2632			1.3340	-1.6897		
Roll, deg/sec			-0.5700			0.5242	1.3988		
c.g., g's			0.1929	15.0000	0.0420	0.3020	0.4130	2.7500	0.0605
#1 axle, g's	12.89		0.2478	7.2500	0.0553	-0.7999		8.0000	0.1340
#2 axle, g's	13.65		0.2178	7.3750	0.0295	0.7094		8.0000	0.1004
#3 axle, g's	15.52		0.1208	13.3750	0.0161		0.9125	2.6250	0.0833
#4 axle, g's	16.25		-0.1375	7.1250	0.0151		1.1496	3.1250	0.1210
HEMTT empty (38,000 lb), 3" obstacle									
Test 133		1.83	3.45-13.39			13.39-16.69	20.03-23.33		
Pitch, deg/sec			0.1906			-0.8468	-0.8540		
Roll, deg/sec			0.4263			0.5503	0.8892		
c.g., g's			0.0725	6.3750	0.0177	0.1864	-0.1368	6.4375	0.0148
#1 axle, g's	14.39		0.1618	6.3125	0.0426	0.3524		2.4375	0.0183
#2 axle, g's	16.32		-0.2072	6.4375	0.1080	0.1737		6.3750	0.0455
#3 axle, g's	21.03		-0.3331	6.4375	0.0395		0.4152	6.2500	0.0300
#4 axle, g's	22.96		0.0934	6.3750	0.0287		0.3713	6.2500	0.0307

(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event: Time Window (sec), and Peak Values	Before Obstacle Event: Max. Freq. Hz	Before Obstacle Event: Max. Ampli.	During Obstacle Event: Time Window (sec), and Peak Values: Front Axels	During Obstacle Event: Time Window (sec), and Peak Values: Rear Axels	During Obstacle Event: Max. Freq. Hz	During Obstacle Event: Max. Ampli.
HEMTT empty (38,000 lb), 3" obstacle (Continued)									
Test 134		1.80	3.44-13.37			13.37-16.67	19.99-23.30		
Pitch, deg/sec			0.0885			-0.8398	0.7863		
Roll, deg/sec			-0.4536			-0.4545	0.6375		
c.g., g's			-0.0454	6.4375	0.0127	0.1305	0.1369	4.8750	0.0203
#1 axle, g's	14.37		0.1418	6.4375	0.0623	0.4005		6.3750	0.0493
#2 axle, g's	16.30		0.1358	6.3750	0.0592	0.2694		6.7500	0.0254
#3 axle, g's	20.99		0.0998	6.3750	0.0219		0.3664	5.6875	0.0330
#4 axle, g's	22.93		0.1106	12.7500	0.0271		0.5418	5.6875	0.0343
Test 135		1.81	3.41-13.26			13.26-16.55	19.82-23.11		
Pitch, deg/sec			-0.0985			-0.7928	-0.8578		
Roll, deg/sec			0.5585			-0.5618	0.8620		
c.g., g's			0.0484	12.8750	0.0090	-0.1577	0.1748	4.9375	0.0202
#1 axle, g's	14.26		0.2511	6.4375	0.0766	0.5432		6.5000	0.0588
#2 axle, g's	16.18		0.1628	6.4375	0.0782	0.3436		6.5000	0.0497
#3 axle, g's	20.82		-0.0819	6.4375	0.0261		0.4714	6.3125	0.0282
#4 axle, g's	22.74		0.0983	6.4375	0.0415		0.4666	5.7500	0.0322
Test 136		4.57	8.37-12.42			12.42-13.83	15.08-16.47		
Pitch, deg/sec			0.2665			1.7945	-2.2789		
Roll, deg/sec			-0.4737			0.7405	2.0605		
c.g., g's			-0.1184	5.0000	0.0245	0.3453	0.5236	2.7500	0.0878
#1 axle, g's	12.92		-0.2101	14.6250	0.0414	-0.8261		5.6250	0.0907
#2 axle, g's	13.69		0.2722	14.2500	0.0562	0.8949		2.7500	0.0877
#3 axle, g's	15.58		-0.1328	15.2500	0.0211		1.0932	2.6250	0.1507
#4 axle, g's	16.33		-0.1250	15.2500	0.0259		1.4993	2.6250	0.1493
Test 137		4.51	8.41-12.46			12.46-13.88	15.11-16.51		
Pitch, deg/sec			0.2645			1.8587	-2.2733		
Roll, deg/sec			-0.2911			0.8263	-2.4896		
c.g., g's			-0.1336	14.3750	0.0260	0.3870	-0.5457	2.7500	0.0953
#1 axle, g's	12.96		0.3411	15.3750	0.0635	-0.8395		5.6250	0.0848
#2 axle, g's	13.73		-0.2808	14.5000	0.0603	0.9759		2.7500	0.0924
#3 axle, g's	15.61		0.1145	14.3750	0.0152		1.3117	2.6250	0.1599
#4 axle, g's	16.36		0.1138	14.3750	0.0219		1.4472	2.6250	0.1639
									(Continued)

Table D-1. Results of HEMTT dynamic tests over low profile obstacles (continued).

Test Number and Instrument Location	Event Mark Times sec	Test Speed mph	Before Obstacle Event			During Obstacle Event			
			Time Window (sec), and Peak Values	Max. Freq. Hz	Max. Ampli.	Time Window (sec), and Peak Values		Max. Freq. Hz	Max. Ampli.
						Front Axels	Rear Axels		
HEMTT empty (38,000 lb), 3" obstacle (Concluded)									
Test 138		4.49	9.08-13.16			13.16-14.58	15.84-17.24		
Pitch, deg/sec			-0.2306			1.8920	-2.4063		
Roll, deg/sec			-0.3597			0.7330	2.1999		
c.g., g's			-0.0928	4.8750	0.0251	0.4073	0.5495	2.6250	0.0938
#1 axle, g's	13.66		0.3927	15.2500	0.0657	0.8490		8.0000	0.1241
#2 axle, g's	14.43		-0.2857	14.3750	0.0632	1.0377		5.7500	0.1029
#3 axle, g's	16.34		0.1102	2.7500	0.0136		1.1627	2.6250	0.1569
#4 axle, g's	17.09		0.1378	15.0000	0.0233		1.4991	2.6250	0.1628

APPENDIX E
REPORT DEFINITIONS

The following are definitions of vehicle and vehicle dynamic terms used in this report.

a. *Acceleration.* The rate of the change of velocity.

b. *Accelerometer.* An instrument for measuring acceleration or for detecting and measuring vibrations.

c. *Amplitude.* The extent or range of a quantity.

d. *Analog.* Data represented by a continuous and measurable voltage.

e. *Center of Gravity.* The point at which the entire weight of a body may be considered as concentrated so that if supported at this point the body would remain in equilibrium in any position.

f. *Digital.* Data in the form of numerical digits.

g. *Fast Fourier Transformation.* A mathematical process for transforming data form a time domain to a frequency domain.

h. *Frequency.* The number of repetitions of a periodic process in a unit of time.

i. *Gross vehicle weight (GVW).* Weight of a vehicle fully equipped, loaded, and serviced for operation including operating personnel.

j. *Hertz.* A unit of frequency equal to one cycle per second.

k. *Natural Frequency.* That frequency which causes the greatest vibration disturbance throughout a system.

l. *Photoelectric Sensor.* An instrument used to detect motion.

m. *Rate Transducer.* An instrument used to measure the rate of movement.

n. *Soft Soils.* Soils which allow significant rutting during vehicle traffic.

o. *Steady State.* A state or condition of a system or process that does not change in time.

p. *String Potentiometers.* An instrument used to measure displacements.

q. *Suspension.* The system of devices supporting the upper part of a vehicle on the axles.

r. *Telemetry.* The process of transmitting data by radio to a distance station, and there indicating or recording the quantity measured.

s. *Time History.* Data collected over and plotted using a length of time.

t. *Traction.* The propelling force developed by the ground-contacting element on a given supporting medium.

APPENDIX F

REPORT ACRONYMS

The following is a list of acronyms that are used throughout this report:

a. A to D. Analog to Digital.

b. c.g. Center of gravity.

c. DNA. Defense Nuclear Agency.

d. FFT. Fast Fouier Transformation.

e. GVW. Gross vehicle weight.

f. HEMTT. Heavy Expanded Mobility Tactical Truck.

g. Hz. Hertz, Cycles per seconds.

h. mph. Miles per Hours

i. MSD. Mobility Systems Division

j. PSD. Pavement Systems Division

k. VEHDYN. Vehicle Dynamics Module

l. WES. Waterways Experiment Station.

m. WIM. Weigh-in-motion

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